SAFE WATER STORAGE

CE290: Design for Sustainable Communities
Final Report
May 14, 2010

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Abstract

This report is a chronicle and analysis of research, process, and findings during the CE 290: Design for Sustainable Communities class about safe water storage in Hubli, India during Spring 2010 at the University of California Berkeley. The report explains the stakeholders for this design project, drawing heavily from a needs assessment executed by a student group HMS in Hubli during the summer of 2009. Based on the needs assessment and a literature review of the issues surrounding clean drinking water in similar geographies and economic situations, the team defined the main goal for the semester: to create a technology that will minimize additional microbial contamination of drinking water after storage in homes. We also rigorously developed a set of design criteria to which we referred back during the iterative design process. In order to meet this goal and design criteria, the team developed four prototypes: water lift, siphon tap, hand-wash station and dispenser. The four prototypes have different features, which translate into varied benefits and drawbacks that are detailed in this report. The report is organized so that product evolution, future work, and cost estimates are all found in the prototype section. In addition to designing and building the prototypes, we spent a considerable amount of time writing a monitoring and evaluation plan that can be executed in Hubli when a group of students do field work there during summer 2010. The team foresees many future opportunities for developing the concept of safe water storage prototypes that limit hand-water contact.

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Background and Context

According to the World Health Organization about 2.2 million deaths occur annually around the world due to diarrheal diseases, mostly in children under five years of age (Sobsey et al., 2002). Most diarrhea causing pathogens are transmitted via the fecal to oral route due to lack of access to safe drinking water and inadequate sanitation.

The project site is Hubli in Karnataka, India. Haath Mein Sehat (HMS), a UC Berkeley hygiene education and advocacy student group, has been working in Hubli since 2007. Residents of Old Hubli, Anand Nagar, and Heggeri (Karnataka, India) collect water from community taps, which receive intermittent water supply from Hubli-Dharwad Municipal Corporation (HDMC). Water supplied to the Hubli area is disinfected at the HDMC plant but residual chlorine measurement in 2009 (HMS, 2009) showed an insufficient concentration at the tap. Water is typically stored within homes for anywhere from 5 to 12 days (HMS, 2009). In the summer of 2009, HMS volunteers, local college students, sampled the water storage containers of 30 randomly selected households in the slum communities of Old Hubli, Anand Nagar, and Heggeri. Organisms indicating fecal pollution were found in the stored drinking water of a large proportion of the sampled households (HMS, 2009; 23).

Microbial dynamics inside a stored water container are quite complex and difficult to predict. However, bacteriological water quality has been shown to decline in several studies due to recontamination (Wright et al., 2004), providing another transmission route for diarrhea-causing pathogens even after initial treatment. Recontamination is affected by size of the storage vessel mouth, collection method, transfer of water between containers from collection to storage, hand-water contact and dipping of utensils during access, bacterial die-off, regrowth and biofilm production within the storage container (Mintz et al., 1995; Levy et al., 2008). In the context of Hubli, recontamination of the water can occur during collection, transport and storage.

Storage is likely the most significant contributor to recontamination as collection and transport takes only several minutes compared to the days spent in storage (HMS, 2009).

The transfer of fecal matter from the environment to the storage container during the water retrieval process likely causes contamination in the home. These transport routes can be deduced from observational data. According to the HMS Needs Assessment Report, complied to assess the necessity of a hygiene education program, 70% of the survey respondents dipped their fingers into the water in the storage container during retrieval (HMS, 2009; 22). In addition, only 8% of survey respondents washed their hands after using the restroom and only 1% did after handling children's feces (HMS, 2009; 30). With such hygiene practices, drinking water could be repeatedly contaminated with fecal pathogens tens of times over the course of storage. Given these findings, an intervention to prevent hand-water contact during access of water from the storage container promises to have an impact on the level of fecal contamination in the drinking water and consequently the incidence of diarrheal disease.

Team Goals

Goal Statement and Evolution

The safe water storage project aims to prevent recontamination of drinking water in the home in order to minimize diarrheal disease transmission routes. The focus is in developing mechanisms to prevent hand-water contact during the water storage phase, as it appears to be the largest contributor to recontamination. The goal statement is shown in Table 1.

Table 1. Evolution of Project Goals

Initial goal statement	–	Create a technology that will minimize fecal coliform count in stored water such that it is comparable to control source water.
Revised goal statement	–	Create a technology that will minimize additional microbial contamination of drinking water after storage in homes.

Fecal coliform testing was abandoned because the levels of microbes depend on several site and user based factors that cannot be simulated with any degree of usefulness.

The team eventually decided to focus primarily on developing technologies that would be culturally relevant, since even a well-designed intervention technology would be rendered useless if it was not adopted and used correctly the target population. The emphasis became human-centered design and incorporating end-user preferences into the design criteria. Evaluation of the prototypes was conducted to assess effectiveness in preventing hand-water contact during water access according to the established design criteria.

Project Deliverables

The team's project deliverables included the following items for the limited scope of one semester:

1. Develop prototypes for hand-free water access that can be used in combination with the range of existing containers and conditions i.e. for various shapes and sizes, containers placed on the floor and tabletops.

2. Advance prototype design to a stage such that cultural acceptability feedback can be collected. The prototypes must look and function similarly to a final product that could be marketed, but they do not have to be ready for final dissemination. This is done to limit the scope of the semester as well as to allow flexibility in design pending feedback.

3. Develop a comprehensive feedback, monitoring and evaluation plan for prototype field-testing in Hubli over summer 2010. Three team members and a group of HMS volunteers are traveling to India for 8 weeks. The eventual goal is to gain more certainty regarding the target market and user preferences in order to redesign a successful product.

Evaluation of Stakeholders and User Needs

A preliminary stakeholder analysis identified the following entities that must be considered for successful implementation of the project: adult women (e.g. mother of household), adult men (head of household), children, shopkeepers or merchants, donors and potential partner non-governmental organizations. The most restrictive users of this technology would likely be adult women and children capable of autonomous mobility, defined as three years of age or older. A table containing the initial stakeholder analysis is attached as Appendix 4.

From the hygiene education needs assessment that Haath Mein Sahat (HMS) conducted in summer 2009, the team gained an understanding about the living conditions of the end users. The target community lives mostly in three slums outside of Hubli: Sadar Sofa, Anand Nagar and Heggeri. Many households consist of over six people Literacy rates are low at about 75% for men and 52% for women, compared to the average for Hubli which is 90% men and 80% of women. Astonishingly, only 10% of mothers surveyed have an education higher than the primary level and 45% report having no education. The most common occupation for women is a homemaker, followed by self employed and public sector. The most common occupation for men is self-employed, followed by private sector (formal) and private sector (informal). The father is generally responsible for decisions about purchases in the household.

The average household has 2.8 rooms and the number of occupants per room ranges from 1/3 to 8 people, averaging 2.4 people per room. Most households have tiled floors, followed by stone floors and then cement floors. The average income of households is 4,000 rupees per month, with the highest reported income at 15,000 rupees and the lowest 550 rupees. One quarter of these slum households report having bank account, which means that they have some facility with the banking system.

Hubli residents have a limited level of understanding about the connection between water and diarrheal disease. A small portion of the population understands the need for clean water (HMS, 2009; 11) and this aspect presents a challenge for the adoption and dissemination of a device aimed to prevent diarrheal illness. Diarrheal illness is also not among the major health concerns in the community: only 5% of survey respondents reported that diarrhea is the most common health concern for their household

(HMS, 2009; 12). A sizable proportion of the respondents, about 35%, believed that the cause of diarrhea is temperature and climate related (HMS, 2009; 13). These findings emphasize the need to rely on product aspiration value and aesthetic appeal to market the safe water prototypes, rather than a health based advertising approach.

Most Hubli residents get their water from a private tap in their yard, or go to a neighbor's house who has a private tap. Only 14% of survey respondents report having a tap in their house (HMS, 2009; 18). Most typically, women are responsible for collecting water, and spend an average of 11 minutes per day on the task. In about one third of the surveys, however, men help collect water as well, and about one-fifth of the households report that children also help (HMS, 2009; 18). This makes it important to focus our prototypes on women, but also keep in mind that male heads of household and children are involved in water.

Shopkeepers and merchants are also stakeholders, in that they could be the ones to carry the initial safe water storage devices in their stores and be involved in the upkeep and maintenance of the items. However, their involvement is not critical to consider at this stage of the project. Eventually, involving the shopkeepers has the potential take advantage of existing social power dynamics within a community. In addition to the members of the Hubli population, other stakeholders include donor agencies, such as the Deshpande Foundation that is based in Boston and is funding some of the activities of HMS in Hubli. The Deshpande Foundation expects to see ten water storage prototypes distributed to slum households in Hubli over the summer of 2010.

Design Criteria for Human-Centered Design

With the defined users in mind, detailed quantitative and qualitative design criteria were developed for the ideal safe water storage retrofit, which are shown in Table 2. The competition was deemed to be the status quo i.e. accessing water by dipping a cup into the water storage container. The prototypes that have been developed are attempts at conforming to most or all of these criteria.

Table 2. List of health and user-driven design criteria for a safe water storage retrofit.

Health Driven Design Parameter: Prevent hand-water contact during water storage in home.	
User Driven Design Parameters	
Adult Woman (Primary User)	*Three year old Child (Most Restrictive User)*
- Transfer from transport to storage container must be less than 1 minute. - Transfer mechanism must be doable by one person. - Access must be quick: equivalent flowrate about 100 milliliters per second. - Materials must be perceived as “clean”. - Must be cheap (pending willingness-to-pay survey data). - Retrofit must not destroy the integrity of the container (no holes).	- Access point no higher than 3 feet: child can comfortably reach no higher. - Must be sturdy and durable: child will cause wear and tear. - Must be stable: child could pull container/ retrofit and cause tipping over. - User interface must be intuitive and operable by the child.

The design criteria are mostly educated guesses by the team to formalize the preferences of target user. Information used to develop the criteria came from interviews with the HMS team, Zachary Burt, and the field contact Devadanam Talapati (HMS employee based in Hubli). It is difficult to say how universal these preferences are because such interviews inherently introduce an opinion bias. The impending field visit is intended to further solidify the design criteria through surveys and focus groups.

Project Progress

I. Prototype Development

An understanding of existing containers was required to proceed with the design process. There is variation in container type, location and use and the team identified two key variables of the existing containers that would dictate the design of the access device:

- The ranges of motion that could be used to operate water access devices were limited by the vertical position of the container i.e container placed on the floor or on a tabletop at waist level.
- Shape of the container would determine access and attachment mechanisms

Among the households surveyed in the HMS Needs Assessment Report, about 78% storage containers were placed on an elevated surface, while the remaining rested on the floor (HMS, 2009; 21). In addition, our field contact in Hubli, Devadanam Talapati did a survey of eight households in the target area. These households had several storage containers for drinking water (range 3 to 9), but were limited to two shapes: cylindrical steel tanks and *matkas* made of various materials. The results of the survey and the accompanying photographs are attached in Appendix 2. The steel tanks are manufactured with a fitted lid and are available in 4 standard sizes. Devadanam was of the opinion that people prefer to access water from the steel tanks rather than other smaller mouthed containers.

Based on the information gathered, we decided to produce prototypes that would fit various shaped vessels for each niche: container on the floor and container on an elevated surface. Particular attention was paid to the straight walled steel tanks as these are most commonly used. Care was also taken to use food-grade material for the construction of these prototypes, as drinking water would come in direct contact with the materials. A comparison of all the prototypes is presented in the last part of this section.

(i) Water Lift

The water lift is most suitable for containers sitting on the floor or a low platform. The current securing mechanism is appropriate for straight walled steel tanks. The process of designing the water lift emerged from the concept of moving a column of water vertically upward and out through a spout. The reciprocating action of a bicycle pump was chosen to drive the water upward, as this action is ergonomically suitable for a vessel on the floor. With these two fundamental design elements, a number of prototypes were made to progressively develop the design, allowing it to evolve over time to accommodate different criteria.

Product Evolution

The water lift version zero (v.0) was created as a miniature version of the water lift, constructed from basic materials available at Ace Hardware in Berkeley. Starting with a 6” PVC tube, the small-scale version proved that water could indeed be lifted up out of a pipe using a combination of washers and rubber rings acting as a piston. Following this finding, a full-scale version, the water lift version one (v.1) was produced, as shown in Figure 1.

Figure 1. Water Lift Version One (v.1).

The bill of materials for prototype v.1 consisted of rubber and steel fittings, a steel rod and plate, along with a pipe. The rubber and steel fittings are arranged on the steel rod to form a labyrinth-like seal. First, two points at the end of the rod must be constrained using hex and lock nuts. A rubber sheet and metal washer are then placed between the two constrained points such that they may float freely between the two ends. The steel rod then rests in the center of the pipe, which has had inlet and outlet holes drilled into its sides. When this device is placed in a storage tank, water enters the pipe through the inlet hole on the bottom end and fills the pipe up to the hydraulic grade line.

Pulling up on the steel rod turns the labyrinth seal into a piston, and the seal bears the weight of the column of water. In this way water is lifted up and out through the upper outlet hole. The water flows from a simple stainless steel faucet affixed to the outlet hole. Users can access water with the lid of their pot on, as lids can be modified to accommodate the lift pipe.

For the water lift v.1, 18 inches was selected as a representative depth of water containers in Hubli based on HMS data on water containers in the area. The scaled up model used galvanized steel pipe with a very rough inner surface. It was at this stage that using metal washers as the seal became infeasible, since the difficulty of creating or finding washers precisely the same diameter as the inside diameter of the pipe was monumental. Instead, better fitting components were cut from a sheet of rubber, and the rate of water delivery was measured to be approximately 100 milliliters (mL) per cycle.

The water lift works because of the small amount of leakage that occurs as the seal lifts water compared to the amount of water in a filled pipe. The operation of the lift is directly related to the difference in elevation between the outlet hole and the hydraulic grade line, and below a minimum level of water using the pump becomes infeasible. This disadvantage is compensated by the fact that households often have one large container for drinking water, and this store is replenished from other available water vessels.

Feedback from the class during the midterm review provided insights into how users in India would be challenged. Firstly, the stroke of the water lift was not easily understood by users. An insufficient stroke produced little or no water while an overly aggressive stroke caused water to come out too quickly. Both of these problems likely presented themselves as a result of large frictional forces within the water lift system. One of the class' suggestions was that the piston rod be inscribed with a colored indicator representing the correct draw length. Such an inscription would be a feature that is sure to present itself on the final model. Secondly, with no interface developed to bind the water lift to the container, drawing water from the container is difficult to control. The friction of the piston as well as the force of drawing water upward lifts the entire device from the container.

The water lift alone cannot solve water storage problems, as a new kind of interface must be designed so that the water lift is compatible with a lid and sits securely on the top of a water container. But setting that aside, the actual manufacturing of the water lift still presented a problem. It would be simple to send out the designs for such a device out to a company to be custom made and rapidly productized, and only later was it found that a commercial version of the water lift, a boat bailer, had already been developed. Fortunately, we were able to obtain a metal version of the old design, and knowledge of its valve seals were incorporated into the next iteration of the water lift.

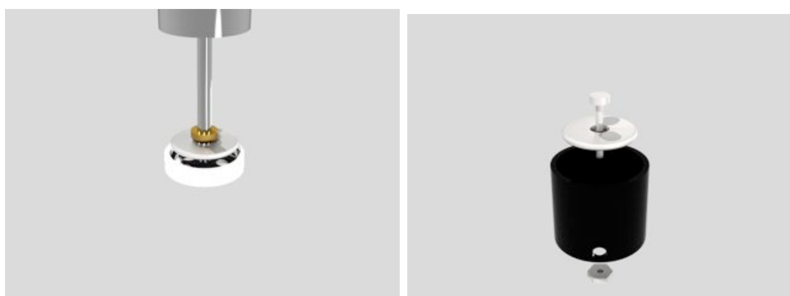

Figure 2: Piston cap (left) and valve cap (right) for water lift v.2

Sending the product out to be made by a third party is against the spirit of sustainable development, though, and the design path turned toward a different course. Sainath's first report described an affinity amongst those living in poverty towards stable employment. A stable wage reduces the risk associated with living in poverty by providing a buffer against market fluctuations. A job would also provide parents with the money required to send their children to school, as well as purchase more than basic products that improve the health of the family. Though the lid interface and user features are still very relevant problems that must be addressed, more research was put into fabricating the device using local methods so that local labor could be involved in producing this health product.

It was assumed that within the city of Hubli, finding a large machine tool like a mill or lathe would be difficult, so the fabrication method would have to avoid heaving machining. The process of welding, though, is commonly found throughout the developing world, and experienced artisans and craftsman can be found everywhere. Local manufacturing of the water lift should tap into the talents and resources of the locals, which at the same time would create a stronger connection between the intended users and the product.

Six feet of polished stainless steel railing tube was purchased to serve as the decorative body for the prototype version two (v.2), as shown in Figure 3.

Figure 3: A CAD model of the water lift v.2

In order to produce fitted valve on the inside of the tube, similar to that of the bailing tube, small collared sections of the pipe were removed and used as a mold. The original plan for these molds were to coat the surfaces with a release agent, then to paint epoxy on in layers so that they would form a perfect fit to the inside of the tube. Then these epoxy valves would have holes drilled through them to give them the functionality of a bailing tube valve. However, the epoxy molds were unsuccessful, and the valves could not be released from the mold using a simple lubricating spray. It is possible that further trials with different polymers and release agents would yield a molded valve, but particular attention would have to be paid to the aesthetics of the valves. The epoxy in the test molds formed rough, irregular surfaces, which would both produce an adverse impression on the user and possibly limit the effectiveness of the valve. Due to this setback, the final version of the prototype used a polypropylene cylinder, which was machined to the correct diameter and used as a valve.

A pipe segment used for the spout would have to be joined to the main body of the water lift, and that process can be done with low-temperature silver soldering. Using a special type of acidic flux and a propane gas torch, two stainless steel components can be permanently joined together, as shown in Figure 4. This method of assembly is consistent with the practices of local welders and craftsman.

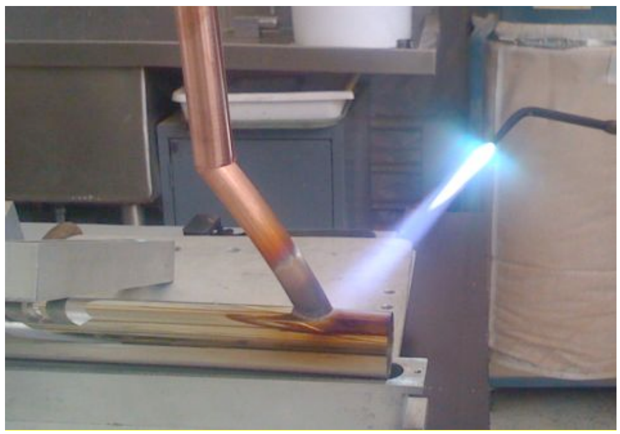

Figure 4: Soldering together the spout on the water lift v.2

Cost Estimate

Manufacturing the water lifts locally should result in the lowest costs possible, if local materials are discovered that can be applied to creating the lift. The most expensive component would be the stainless steel tube, which if purchased domestically in the United States would cost roughly \$7.50 per product (6’ at \$30.00 and 18” for each water lift) with additional costs estimated from bulk supplies: metal washers, thermosetting plastics or extruded high-density polypropylene, silver solder, propane gas, and steel piston rods not exceeding 100% of the tube price. A rough estimate of the cost of manufacture of this product would then be around \$15 dollars, which at 675 Rs. is nearly 17% of the average income of a Hubli slum resident.

(ii) Siphon Tap

The siphon tap prototype is designed to be used primarily for containers at an elevated surface and can be adapted to a container of any shape. The inspiration for this design came from a simple hose siphon, which is typically used to empty car fuel tanks or fish tanks, once it has been primed. The concept is simple: use the existing hydraulic head to drain water from the vessel to an access point that is lower than the water level in the container. The only energy required for this process is to move the water over the lip of the container and fill up the hose, which is called priming the siphon. Once primed, the water will continue to flow until lifted to a position higher than the water level in t he container or stopped by an external force, such as a tap or valve. The main technical challenge to use this concept for a water access prototype was to incorporate the priming action into the device and also to have the ability to start and stop the flow of water.

Product Evolution

The siphon tap is suitable for containers that are placed at waist height or higher and would bring the access point within a child's reach. The device consists of flexible tubing connected to a bellows pump and two one-way flow valves. The bottom valve also acts as a siphon breaking device. In this way, the device is not a true siphon because the water has to pumped by pressing down on the bellows. A proof-of-concept version zero (v.0), shown in Figure 5 was constructed using off-the-shelf valves and ½" flexible tubing. Prototype v.0 was originally configured to hook onto the edge of any straight walled container and delivered about 50 milliliters with each stroke. The device contained two ball-and-spring valves, each rated for pressures significantly higher than required. It was also made of plastic, bulky and not aesthetically pleasing.

Figure 5: Siphon tap v.0 (proof-of-concept)

For the next version (v.1), attempts were made to incorporate the valves into the body of the device and use copper in order to obtain a more polished look. Siphon tap v.1 can be seen in Figure 6, without valves or the flexible hose. A decision to construct in-line valves was made to conform to the aesthetics of a single smooth copper pipe, that would likely be well-received by the target community. Copper was primarily chosen as the construction material because copper pots are used in Hubli households indicating acceptability of the material for drinking water applications (Appendix 2), and the metal can be also be machined easily. A larger bellows pump was acquired to increase stroke volume.

Figure 6: Siphon tap version one (v.1)

Siphon tap v.1 used the volume of air in the bellows to push a comparable volume of water (accounted for air compression effects) through the pipe and out the mouth. The upstream valve prevented water from back-flowing into the container during the down stroke and the downstream valve prevented air from entering through the spigot during the upstroke of the bellows. During the operation of v.0, water accumulated inside the bellows during operation and there was concern about any ensuring bacterial growth. Therefore for v.1, the design was modified to maintain a volume equivalent to the bellows between the two valves. The rationale was that water was sucked up into the bellows because some of the original air in the bellows was pushed out through the spigot in the down stroke. Therefore, if the volume contained in the pipe between the two valves was at least the equivalent of the bellows volume, then water would not accumulate in the bellows. Basic calculations determined the volume needed and thus the size of the pipe (Appendix 5), which came to be 7/8” outer diameter (copper size pipe ¾”). The pipe was bent into an S-shape appropriate valves were incorporated.

Several off the shelf siphon systems were disassembled and analyzed to determine the best design for the valves. Simple ball valves were made by using a brass housing that fit exactly inside the pipe diameter. The upstream valve contained a ½” diameter buoyant polypropylene ball that seats against the brass housing during the bellows down stroke. The ball is kept inside the brass housing by a small brass pin, as shown in Figure 7.

Figure 7: Upstream valve for siphon tap v.2

The downstream valve contained a stainless steel conical spring and denser-than-water steel ball and is shown in Figure 8. The base of the conical spring is the same diameter as the inside of the brass housing. The other end of the housing has the ball seat, machined to the appropriate dimensions. The downstream valve also prevents natural siphoning action because the spring cannot be compressed by a stationary column of water as demonstrated by preliminary calculations (Appendix 5).

Figure 8: Downstream ball-and-spring valve for siphon tap v.2

Pipe bending was accomplished after annealing the copper pipe to red-hot temperatures with an acetylene flame and then placing it in a pipe bender. We discovered that pipes with thin wall thicknesses such as copper pipe type M would deform upon bending, resulting in unsightly wrinkles. With help from Jonathan Slack, we were able to bend slightly thicker copper pipe (type L), after freezing water inside it and capping the end to provide a structural force from inside the pipe. The siphon tap stand was made by soldering together standard copper pipe fittings and a pipe lengths of the an arbitrary ½” pipe size. For v.1, the spigot end was bent by 90 degrees and the hose end was bent to 60 degrees from horizontal.

Several lessons were learned during the construction and testing of siphon tap v.1. This version did not operate well; there was considerable difficulty in priming the device and the upstream valve did not operate well with only air (buoyant ball needed water and air to seat). The air from the bellows migrated back into the flexible hose, instead of staying inside the designed volume between the valves, breaking the priming action of the siphon. The 3/8” flexible tube was also too big to allow effective siphoning action. Also, considerable precision was required to make valves that operated as intended.

Siphon tap version two (v.2) was constructed to rectify some of the issues encountered in the performance of v.1 and is shown in Figure 9. The pipe shape was modified to an upside down U, such that all air in the system would naturally migrate to the bellows.

Figure 9: Current iteration as siphon tap v.2

To improve the upstream operation, the constraining pin was moved closer to the polypropylene ball, giving the ball a very small range of motion. An arbitrarily smaller flexible hose diameter was used to test v.2. This version worked significantly better than v.1, rendering about 110 milliliters with each stroke. The siphon primed reasonable quickly, however the downstream valve required considerable force to open.
Formal evaluation of the current version of the siphon tap against the design useful for containers on an elevated surface and can bring the access point lower for easier child access. It is adaptable to several different containers and situations. With a few modifications, this version can be field tested in India this summer. Overall feedback from the target user would enable us to make informed design decisions such as desired flowrates, material preference and aesthetic appeal.

Future Improvements

Next steps in the improvement of the siphon tap include using a smaller pipe and flexible hose diameter. Smaller pipe diameters would make the device cheaper as well. It will also allow the device to prime quickly. Better valves must be used and these can either be purchased from a supplier or custom made using the experience from v.1. The valves could be custom-ordered from a supplier for an eventual mass-produced product. There is little outside control for the upstroke of the bellows and inserting a spring inside to make the strokes faster could be explored. Alternative designs for the stand could include a disk and other materials, such as quality platics, that could be cheaper. Longer term testing of the siphon tap should be done to determine any water quality implications of using this device and having water accumulating into the bellows.

Cost Estimate

An estimated cost for the siphon tap v.2 is about $20. Materials used for the construction of this prototype include ¾” copper pipe for the body, ½” copper pipe for stand, pipe fittings (tees and end caps), bellows, brass pieces for valve housing, ½” steel ball, ½” polypropylene ball, conical spring and brass fitting to attach the bellows to the pipe. Most materials were bought at retail price in significantly larger quantities than were consumed for the prototype.

(iii) Handwash Station

The portable hand washing stations that are commonly paired with outhouses at outdoor events first inspired the handwash station prototype concept. The water delivery mechanism involves a foot pump that moves water from a storage tank situated at floor-level to an elevated faucet. Below the faucet, excess water is captured in a “waste” basin. This device is a stand-alone unit and can be paired with a container of any shape.

Product Evolution

A proof-of-concept model can be seen in Figure 10. The hydraulics of the pump and tubing system were tested first, and it was discovered that the height/placement of the outlet was rather flexible—functional in a range of 0-4 ft. tall. The frame was constructed with standard pieces of wood and bulk fasteners (screws), using a saw, power drill, and vice. The height of the frame can be modified according to preference, as long as the unit is sturdy enough to stand upright. The width of the frame should be determined by the width of the largest storage container that will be used with this device, also accounting for the width required to place the container inside the frame with one's hands. Ensuring that the frame rests flush with the floor proved to be rather difficult, from an amateur wood-worker's perspective, but small rubber caps can be placed in the corners for balance. The countertop was made using a standard piece of particleboard, cut to size. Holes were then drilled into the board according to the placement of the faucet. All-purpose cement was primarily used to keep the tubing attached to the faucet inlet and to the pump valves. However, silicon adhesive was also used to prevent leakage at the tube-valve connection. The end of the tubing that draws water from a storage tank is weighed down with a long, rigid piece of plastic that fits flush with the outer diameter of the tube. Finally, the foot pump rests on a small piece of particleboard that remains unattached to the frame.

Figure 10: Handwash station proof-of-concept model

The primary goal of this model is to prevent all contact between the users hands and the water within the storage container during access. Depending on the lid used to cover the storage tank beneath the unit, water access can be entirely streamlined to a simple foot action. The drawbacks of this particular prototype include: a flowrate lower than the design intention, larger space requirement, and unsteady pumping motion. Some challenges we encountered were: finding a pump of the appropriate size and finding tubing that would form a water-tight seal with the valves. The current version makes use of standard 3/8” plastic tubing and the owner’s existing vessel as a storage basin, thereby reducing the cost of production. The advantages of this model include: simple aesthetic appeal and dual-purpose functionality (this model promotes both handwashing and prevents hand contact with stored drinking water).

Future Improvements

There are a number of improvements to be made with regard to functionality and user interface of the handwash station. First and foremost, the access time needs to be decreased dramatically. Our model currently averages a flowrate of 20 mL/s, instead of the desired 100 mL/s. Secondly, the faucet used in the prototype does not need to be as elegant or intricate. The pre-fabricated faucet was used solely out of convenience. However, we recognize the opportunity to reduce the overall cost of the unit by using a more economical faucet. There is also potential for the faucet to be made of a sleek and sturdy plastic material (polyethylene terephthalate or polypropylene). Regardless of material, the faucet will still have a curved, aesthetically-pleasing shape, to enhance the aspiration value of the product. Additionally, the glass bowl used for the prototype can be replaced with a less expensive bowl or even a bowl already owned by the user. To prevent biofilm growth, the foot pump valve orientation should be modified to prevent water from flowing inside the chamber. Lastly, the foot pump should be more integrated with the entire unit as a whole, to enhance aesthetic value.

After gathering initial feedback from community members, especially considering cultural appropriateness and user friendliness, the established health-based design criteria will be reassessed. In turn, future prototype design will be directly based on feedback from the community.

Cost Estimate

The materials list for the prototype includes 3/8” hose tubing, wood, a bowl, faucet, rigid plastic tube, air foot pump and pipe fittings. The proof-of-concept model, shown in was made of a low-density polyethylene plastic, and the tubing was 3/8” diameter flexible plastic tubing. The current version has less counter space, but also has a built-in soap dish (a 3x5” section of textured polyethylene), to further promote handwashing. Though the manufacturing cost will increase with the plastic model, the polyethylene shell is low-density and the design is relatively simple. The overall cost per unit is difficult to estimate at this point, because it largely depends on the amount being manufactured. User feedback will also dictate the type of materials we are limited to in our design. Therefore, the cost will primarily depend on results from the first iteration of field testing. Ultimately, our goal is to keep the price of the final version of the handwash station under $10 per unit. With large-scale manufacturing and direct materials sourcing, we believe this goal is attainable for future handwash station models.

(iv) Dispenser

Early in the semester, our team contacted Rieke Packaging, a UK based global supplier of dispensing solutions to a multitude of product manufacturers around the world. We received a few samples right before the midterm presentation and were able to dismantle one item and determine its operational mechanisms. Reike Packaging has suppliers in India as well and there is potential for setting up partnerships in the future. A 100 mL size dispenser is shown in the Figure 11. The product consists of a molded plastic body containing a valve system. The enclosed volume within the plastic body expands when it is pulled on, drawing water up from the storage tank through the inlet valve. Pushing down on the body closes the volume, forcing water through the outlet valve and out from a dispensing tip. The operation of the pump is easily understood, and the aesthetics are sleek and elegant. This makes it an excellent commercial candidate for a contact-free water dispensing device.

Figure 11: Pre-packaged 100mL dispenser

The pre-packaged dispenser presents an option that can be presented to Hubli residents during the summer 2010 to collect feedback on its cultural acceptability. One caveat is that using the dispenser requires that the plastic body be fixed to a lid of some kind, to provide the counter force needed to pull water up out of the tank. Future action is needed to find a suitable solution to the lid problem to meet both the dispenser's and the water lift's needs. It is the hope of this team to reduce production costs by seeking out local resources. During the summer, an inventory must be taken of the manufacturing capacity of the city of Hubli. This survey will evaluate whether the city has enough industry to support the production of a health-improving product for its citizens.

(v) Prototype Interface with Existing Vessel

Each of these prototypes must also interact with a lid, and for certain models, this introduces new challenges. For instance, when the device fits onto the lid, the lid must still be able to prevent foreign objects from falling into the container. Second, the action of drawing water out of the tank puts forces on the water. Depending on the design, these forces can be balanced externally or internally. The handwash station and the siphon tap are examples of externally balanced devices. The pumping action takes place away from the container, so forces are exerted on a stand or base. The two designs require no additional retrofits to existing container because an opening crevice less than an inch wide is all that is needed for hose penetration. Existing container lids can be left cracked open or drilled with a small hole for a better fit.

The water lift and the dispenser, on the other hand, have to translate operational forces to the container. If there were no way of transferring the force, the action of drawing water would be more difficult than simply lifting the prototype off the container, which accomplishes nothing. The waterlift solves this by using a bracket to transfer forces directly to the container, without securing the lid. A solution for the dispenser could also be developed using the same method. Holes would have to be drilled into the lids, but the problem of securing the lid to the tank is avoided.

(vi) Prototype Testing and Summary

A formal evaluation of the four water storage prototypes against the established design criteria in Table 3.

Table 3: Prototypes ranked against design criteria and each other

	Design Criteria	*Water Lift*	*Siphon Tap*	*Handwash Station*	*Dispenser*
Primary User: Adult Women	One person operation	Yes, two handed	Yes, two handed	Yes, one handed	Yes, two handed
	Ideal Access: 100 mL/s	200mL/ stroke	110 mL/ squirt	20 mL/ squirt	100 mL/ stroke
	"Clean" Materials*	Stainless steel & copper	Copper, brass, plastic	Plastic, wood	Plastic
	Inexpensive*	Prototype cost: ~ $15	Prototype cost: ~ $20	Prototype cost: ~ $30	Price: ~ $9 + retrofit cost
	No holes in container	Potentially in lid	none	none	Potentially in lid
	Access point <3 ft high	~ 5 in. above vessel top	Adjustable, below vessel	40 in. high	~ 5 in. above vessel top
Secondary User: Child aged 3 years or older	Sturdy, stable	Yes, once secured	Yes, built-in stand	Yes, stand-alone unit	Likely, once secured
	Intuitive user interface*	Yes, inviting spout	Yes, inviting bellows	Misleading faucet dials	Likely, looks like tap
	Operable by child*	Likely	Likely	After height adjustment	Likely (easy operation)

* Specific parameters unknown and to be determined during field testing. Design done to the current state of knowledge regarding user preference and cultural acceptability.

II. Field Testing Plan for Summer 2010

(i) Pilot Monitoring and Evaluation (M&E)

During the second part of the semester, the SWS team began to construct a monitoring and evaluation strategy for the prototypes that we have been developing this semester. We believe that understanding the target population's response to the prototypes, will aid in the iteration or development of a more effective product. Because several members from the UC Berkeley community will be traveling to Hubli this summer and will be charged with carrying out the monitoring and evaluation protocol, we have developed our monitoring and evaluation strategy under real constraints. Firstly, we are limited by time. The HMS team will be working in Hubli this summer for three months from the end of May through end of August, so we needed to design an evaluation system that could mostly occur during that time frame. Secondly, the summer budget is limited by the grants HMS receives, so the potential for hiring professional enumerators to execute the evaluation is limited. Thirdly, we hope to take advantage of the HMS infrastructure already in place in Hubli, such as the program coordinator based in Hubli, Devadanam Talapati, and the water quality testing laboratory.

Evolution of M&E Plan

In order to devise our monitoring and evaluation strategy, we began by speaking with several people on campus who have past involvement in point of use water evaluation studies. Tom Clasen, one of our project mentors, helped us identify three goals for our study: user preference, willingness to use, and water quality. He also pointed us towards several literature references that detailed the goals and logistics of past studies. Jill Luoto, a Ph.D. candidate in the Department of Agricultural and Resource Economics, was very helpful in offering anecdotes and lessons based on her experience designing and carrying out similar studies in Kenya and Bangladesh. Luoto has experience working on comprehensive studies to collect data that could be analyzed to determine statistically significant patterns, and offered advice about writing and testing surveys and the difference between local and foreign enumerators.

After conversations with HMS team members and our advisors, we decided that the general goal for the monitoring and evaluation strategy this summer would be to collect both qualitative and quantitative data. However, the quantitative data sets will be too small for any reasonable statistical analyses, due to time and resource constraints and the fact that the project is in the very early stages. Our goal is to get a better sense of whether Hubli residents demand a safe water storage device in the household, and if so, what are desirable design aspects of such a device. This study can lay the foundation for more work at UC Berkeley during the 2010-2011 academic year and future summer field work.

M&E Study Plan

The team has carefully designed a three-part study to be carried out in the households of Hubli. We will work with Devadanam, the HMS contact who is based in Hubli, to enroll forty families in the study. We do not intend on paying the families for their participation, but we will give them a free prototype of their choice at the completion of the study. In fact, some people have recommended that we ask families to pay a nominal amount for the safe water storage prototype study, as our end goal is to attribute a market-rate price for the prototypes. We have decided not to do this because of the early stage of the study.

Ten families will receive prototype 1 (siphon tap), ten families will receive prototype 2 (water lift), ten families will receive prototype 3 (dispenser), and ten families will receive no prototype and will act as the control. Each of the families will be given a basic tutorial on how to use the prototype. The tutorial will be executed by a HMS member and a Hubli resident, and will consist of a brief explanation of why the safe water storage device can help with health issues. It is important for the target-user to understand the health based motivation for using such a device, even though the emphasis has been on adapting the look of the devices to their aesthetic preferences.

1. User Preference Study

The first study is a user preference study. We will be evaluating which of the three prototypes Hubli residents like best and why. The prototypes will be rotated through each family after one or two weeks. Ideally, we hope to have the households use the prototypes for two weeks, be we understand that there are time constraints to the summer, and have therefore decided to designate a time range. After one to two weeks, each family will fill out a survey about what they liked/disliked about the prototype they were just using. At the end of the four rotations, each family will fill out a final survey that focuses on ranking the prototypes and comparing qualities of each.

There are several issues that we expect might skew our data for the user preference study. For one, neighbor interaction might affect our results. Neighbors that have different prototypes can potentially talk to each other and discuss attributes of the different prototypes and sway their opinions. Jill Luoto said this was one of the main concerns in her study in Kenya; she chose families that were far enough apart geographically that it was hard for them to talk. Additionally, because of the short time frame of the study, families will not really have time to "settle into" using the product. They might be especially eager or disinterested in the prototype because it is only around their house for a limited time.

2. Device Acceptability and Usage

The second part of the study is designed to see if people are using the prototypes. Our questions is: once the prototypes are distributed in the homes, are people employing them to get water from the large steel containers? We plan to study this by conducting unannounced drop-ins to the households participating in the study, and having a set of criteria to determines whether the prototype is being used. Initial ideas for these criteria include the following questions:

- Is the prototype attached firmly to the primary steel container?
- Does the prototype appear to be wet?
- Does the family verbally report using the prototype during their last withdrawal of water from the household container?

We expect these drop-ins to be as short as five minutes. It is important that these drop-ins are unannounced, and should be done at random points during the one or two weeks that the families live with the prototypes.

3. Water Quality Testing

The third study will include water quality testing, comparing the fecal coliform counts from the households using prototypes to those from households any prototypes. We will ask all the Hubli families participating in the study about the specific municipal tap from which their water was obtained, and proceed to analyze water samples from their containers and the tap. It is important for water quality testers to keep track of how many days the water has been stored in the house. The goal of this is to set a baseline for how well the prototypes prevent hand-water contact and thus how effectively they can decrease fecal contamination in the drinking water. We will do our water quality testing at a lab that HMS will set up. The lab was running last year and is in the town of Hubli, so additional water quality testing equipment is unnecessary.

One major issue that has been brought to our attention is that "courtesy bias" may skew our results tremendously in all three facets of the study. Courtesy bias is when families respond to the surveys and questionnaires according to what they think the enumerator wants to hear instead of their actual opinions. Jill Luoto really encouraged us to not have UC Berkeley students involved in administering the survey or doing drop-in house visits because this will taint the results. She suggested having our community contact, Devdanam, make most of the household contact, in addition to hiring university students to help him. We are currently discussing the logistics and costs of hiring enumerators.

4. Focus Groups

After speaking with the HMS group and consulting the literature, we have decided to supplement our household study with focus groups. Focus groups provide a way to get more feedback from more people, albeit foregoing some of the objectivity that individual participants can have. We can gather Hubli residents to do focus groups primarily about our first goal: learning about user preference. A group setting is likely also useful for obtaining willingness-to-pay estimates. We will have themes to the focus groups, such as women, school children, or head of household users. We will not be able to use focus groups to determine the second two goals, and will thus remain with the household study method.

(ii) Early implementation Idea

While it is premature in the trajectory of our project to formulate concrete ideas on how to implement the safe water storage prototypes, we have been in constant dialogue throughout the semester about ideas that we would like pass on to the next group, both over the summer and in this class. Our ideas fall into two main categories: branding/marketing and distribution. Many of the ideas are dependent upon existing conditions and preferences, and thus the team traveling to Hubli this summer will explore them further.

For branding, we have considered putting a sticker on the device. The sticker would serve many purposes. For one, it will be an intricate, interesting, and brightly colored design that will hopefully add aspiration value to the water storage device. Secondly, the sticker will serve as a branding mechanism, and will encourage Hubli residents to recognize the safe water storage device as something with a special, healthy purpose in the household. Finally, with the right design, the sticker could be an educational tool that links using the safe water storage device with improved water quality and thus prevention of diarrheal illness.

To begin thinking about the potential of this sticker, we made some mock-ups. We took drawer liner that we bought at Home Depot and laser cut out the shape of a water bottle. The sticker can be applied to the outside of the device. Laser cutting stickers is relatively simple, in that one just needs an AutoCAD file and a laser cutter (UC Berkeley Architecture Department has two laser cutters). During the midterm design review, we asked our classmates to brainstorm ideas of what might symbolize "clean water" in Hubli. Ideas included the Himalayas, an iconic way of showing the

Ganges River, and rain. During the summer, we hope a group will conduct a focus group on what other symbols represent health to Hubli residents.

We have also started to think about potential distribution mechanisms for the water access device. The distribution method must ideally make use of the existing cultural practices, and thus we need to gain information regarding existing systems. Several ideas were generated over the course of the semester to accomplish dissemination of the ideal water access device:

- Selling the device in the stores in Hubli that sell everyday household goods;
- Employing a team of device retrofitters to go door-to-door;
- Setting up households with the safe water storage device,
- Using major neighborhood and village gatherings as a place to distribute the storage devices; and
- Setting up a kiosk in a prominent neighborhood public space whereby households can bring their steel containers to get retrofitted with the device.

All of these distribution systems would have a price attached to them, and we encourage future groups to consider distribution pricing in these models. To jump start the pricing process, we will include a question in the user preference household surveys and the focus groups about how much the users would be willing to pay for the devices. Based on this information, we hope to get a sense as to whether the parts and labor cost to manufacture the devices is on par with the price people are willing to pay.

Conclusions

Several important lessons were learned over the course of the semester while working on the safe water storage project, most of which lead us to further questions that we hope will be explored in the future. We learned that our designs must be flexible so that they can be modified in the field. This includes flexible construction design, materials, and even concepts. This is why several different prototypes will be tested over summer 2010 instead of just one. Secondly, we have learned the work on this project will never be done. We see our work from this semester as the first phase in a hopefully long project. There is a tremendous amount of work that needs to be done in terms of monitoring and evaluation, redesign and price, marketing and distribution, before these very early prototypes can be effectively scaled up.

It is extremely important to establish strong connections with local partners and maintaining a presence in Hubli around the safe water storage issue. Devadanam Talapati, the Haath Mein Sehat (HMS) project coordinator in Hubli, was extremely helpful in providing us information about user preferences and existing conditions. Similarly, it is important that we find some way to have a sustained presence in the area so that the people in Hubli who might invest time in our study by filling out surveys or talking with Berkeley students feel vested in the project. HMS student volunteers are already a sustained presence there as they as they return every summer for existing hygiene education programs in local schools. HMS also enlists year-round volunteers from local universities to continue the hygiene education program in the absence of the Berkeley students during the academic year. This existing infrastructure is essential for an effective safe water intervention.

We have also concluded that the intervention technology needs to be coupled with health education. We recognize that a safe water storage is a preventative system, and the people will only be inclined to go slightly out of their way to take the extra precautions if they understand the connection between the bacteria found in contaminated drinking water and diarrheal illnesses.

Possible Future Research Areas

There is still a considerable amount of work to be done on each prototype. Materials and design can be improved to maximize efficiency and reflect user preference. We anticipate, however, that after testing the prototypes in the field, we will have an opportunity to reincorporate this feedback into the design.

Moreover, we hope that more work can be done on the lid issue. Thinking about how the pumps and the lids will be integrated is a major part of the design, and one upon which we barely touched. Another group could focus on increasing the integrity of this connection, and investigating how to retrofit the existing lids of the steel containers.

There are a few other prototypes that we talked about developing, but did not get to because of time constraints. For one, the ladle idea was something that we brainstormed as a team, and got feedback on from the other HMS members, but did not have time to build in prototype form. Our idea for this was to make a modified ladle – probably one with a very long handle that could attach to the lid or bucket. The long handle would discourage hand-water contact. We are attracted to this idea because it directly draws on existing user habits, and thusly we would only be asking for a very limited behavior modification. We have also heard anecdotally from a Blum Center member that a long-handled ladle was used in her town in Northern India.

A second prototype that we discussed was making a knock-off of an existing safe water device, the Pure-it. The Pure-It is made by Hindustan Unilever, costs about $45, and is a water treatment device with high aspiration value. We thought of making a storage device that looked like this popular filtration device. A third prototype that we discussed was a combined storage and treatment device. A treatment device with an in-line disinfectant, that doses the water appropriately while also providing safe storage, would be a worthwhile idea. We did not have time to explore this concept during the semester, especially since numerous such devices already exist.

We recognize that safe drinking water is an issue that can be addressed from numerous perspectives. We want to highlight a few totally different ways to address safe water storage that we did not pursue, but quite possible could be viable solutions. We could have focused on a improving the treatment done by the utility company before putting water into pipes, improving the containers used for transportation from the tap to the home, or come up with a user friendly treatment method that is more effective than just pouring water through a sari.

Acknowledgements

The SWS team would like to thank the following people for their feedback, time, advice and encouragement throughout the semester. Names are listed in alphabetical order.

Susan Addy (Instructor CE290);
Zachary Burt (Member HMS; Ph.D. student, Energy and Resources Group),
Thomas Clasen (Visiting professor, London School of Hygiene and Tropical Medicine);
Howdy Goudey (Building Technologies, Lawrence Berkeley National Laboratory);
Jill Luoto (Ph.D. student, Department of Agricultural and Resource Economics);
Johanna Mathieu (Graduate student Instructor, CE290);
Kara Nelson (Professor, Civil and Environmental Engineering);
Jonathan Slack (Building Technologies, Lawrence Berkeley National Laboratory);
Devadanam Talapati (HMS employee based in Hubli, India);
HMS Team (current and previous members for their compilation of knowledge).

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Appendices

Appendix 1: HMS Needs Assessment Data and Analysis

Appendix 2: Hubli Household Survey by Field Contact.

Appendix 3: HMS Container Field Observations Document

Appendix 4: Stakeholder Analysis

Appendix 5: Siphon Tap v.1 Calculations

Appendix 1:

HMS Needs Assessment Data and Analysis

Haath Mein Sehat

Needs Assessment Data and Analysis

Hubli, Karnataka, India

July 23, 2009

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Introduction

Haath Mein Sehat (HMS) is a student group from the University of California at Berkeley whose mission is to improve the quality of life in low-income communities through safe water, health and hygiene education, and access to sanitation. HMS is run by student volunteers from the U.S. and India, and it has been operating in the slums of Mumbai since 2004.

During the summer of 2008, HMS expanded to the city of Hubli in Karnataka. The water access and quality, the housing conditions, and the health concerns and perceptions of slum residents in Hubli are very different from those of slum residents in Mumbai. Therefore, our first step was to conduct a needs assessment of our target neighborhoods in Hubli to ensure that our program is tailored to suit the needs of these communities. The most appropriate and successful interventions are those that are designed to address the specific needs and concerns of the community at hand, not panacea treatments that are applied blindly across all situations.

On the recommendation of several local doctors, we decided to begin working in three low-income neighborhoods: Sadar Sofa, Anand Nagar, and Heggeri. During the summer of 2008, we accompanied translators to conduct a total of 73 baseline needs assessment surveys. These surveys were very extensive, covering everything from basic demographic information to water access and use to sanitation and hygiene practices. At the end of the summer, we trained 7 college students from PC Jabin Science College in the techniques of epidemiological surveying. These students continued to visit these same households throughout the year to conduct short follow-up surveys to get information about seasonal incidence of diarrhea.

In addition, we trained 20 biotechnology students in water quality testing so that they could conduct tests for pH, chlorine residual, total dissolved solids (TDS), turbidity, and quantity of E. coli and total coliform. These students visited 20 of our surveyed households throughout the following year and collected data about their water quality and levels of contamination.

All of the epidemiological surveying students and the water quality testing students have completed their data collection and received certificates in June upon supplying us with the data, which we have now analyzed fully. The information that follows is a summary with analysis of the full results of these programs. This information has proved highly valuable to tailoring our intervention to best serve low-income residents of Hubli, and we will indicate where appropriate how this data has helped to shape our strategy.

Survey Data and Analysis

A full needs assessment survey was conducted in a total of 73 households in Sadar Sofa, Anand Nagar, and Heggeri between the months of July and August 2008. For each survey, at least one HMS member was accompanied by one trained translator to conduct the survey. Questions in which the wording of the question was particularly important were first written in Kannada to ensure that the translators asked these questions in exactly the same manner uniformly across all the surveys. On all charts and graphs, the number of respondents is listed because not all interviewees answered every question.

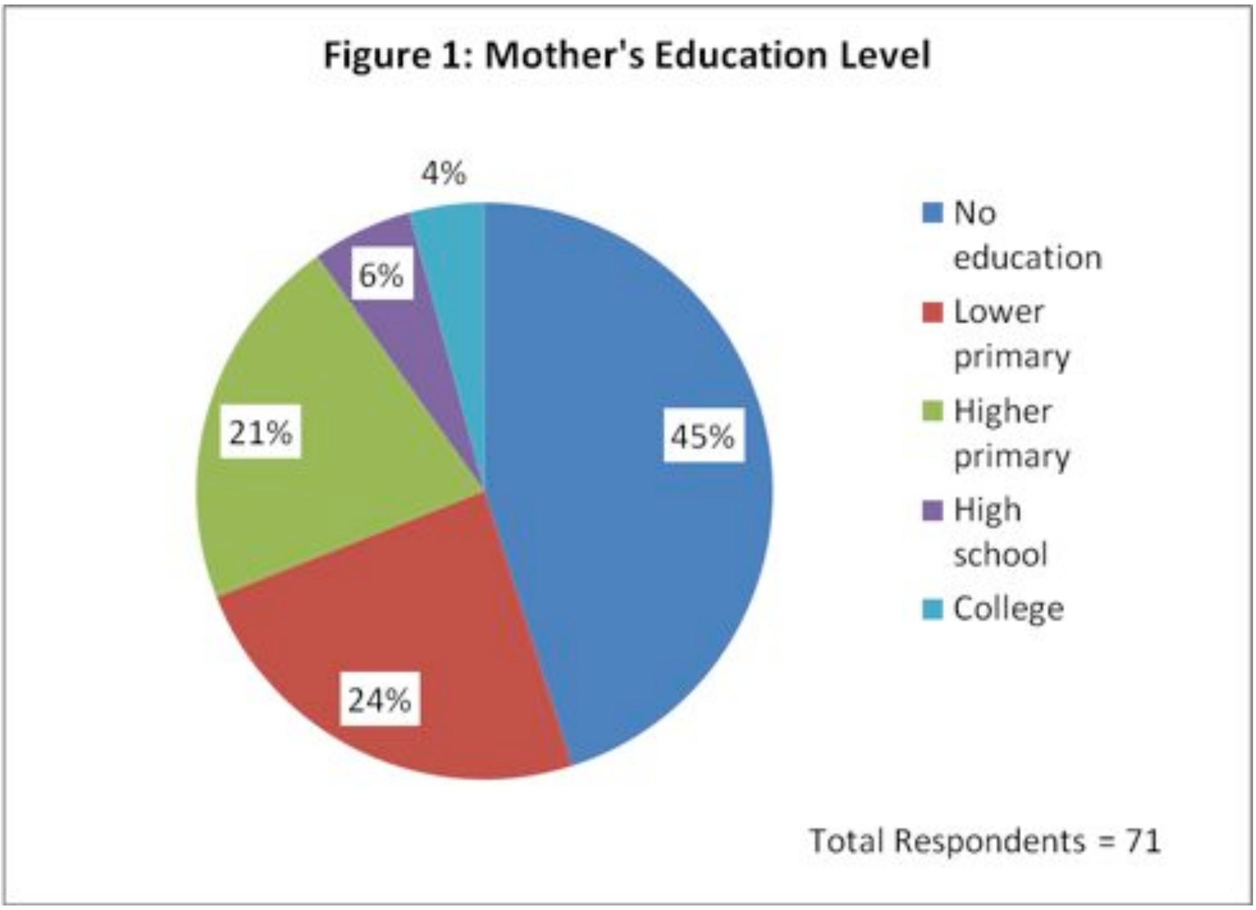
Characterization of Slum Households

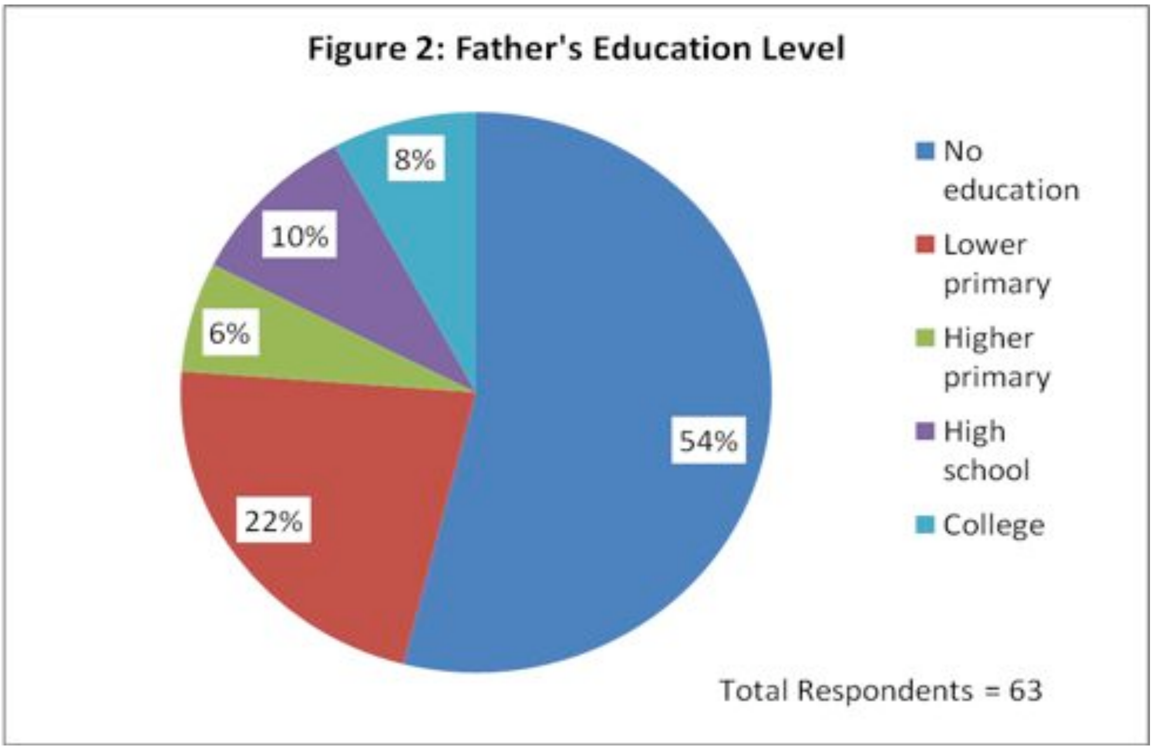
We surveyed a total of 73 households, spread evenly across the three neighborhoods of interest: Sadar Sofa, Anand Nagar, and Heggeri. Of the respondents, 29 are male and 44 are female, with an average age of 38.

The surveyed households have an average of 6.6 people living in the home, which on average is composed of 1.8 men, 1.9 women, 0.8 children under age 5, 1.3 children between age 5 and 15, and 0.8 children over age 15.

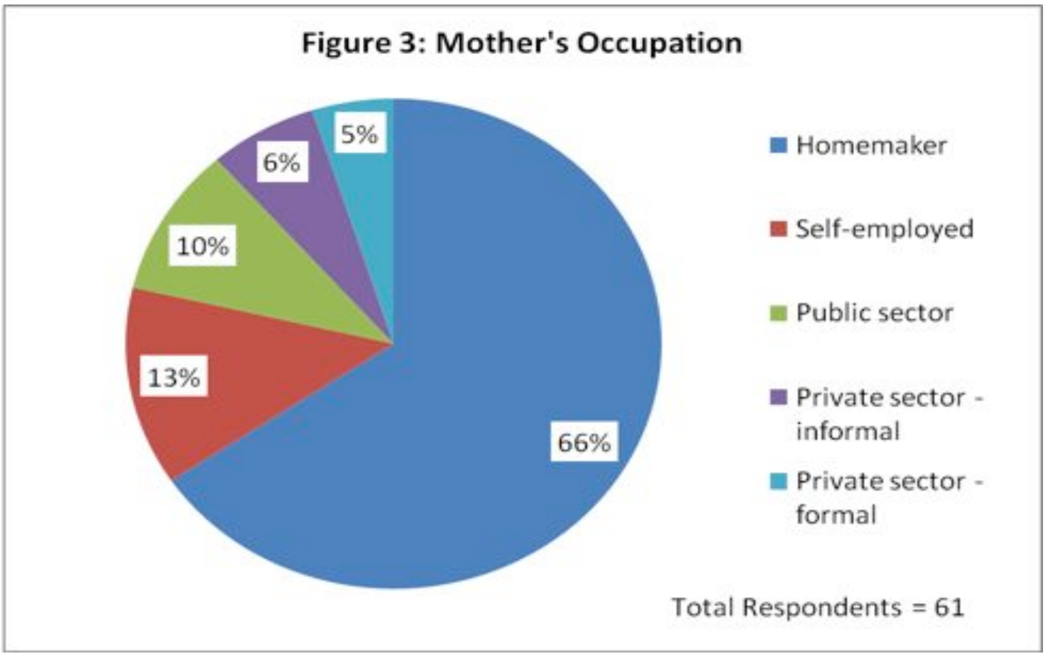
Literacy rates were surprisingly low: 75% of men and only 52% of women reported being able to read and write. The Center for Multi-Disciplinary Development Research (CMDR) survey found that the city-wide literacy rate for Hubli in 2006 was 90% for men and 80% for women[1], so our data indicates that we are working with a particularly illiterate subset of the population which will require non-written methods for distributing information. As a result, we have designed our informational pamphlets and our results sheets to be as picture-based as possible. Our treatment options pamphlet provides pictures of all of the treatment methods, and drawings showing appropriate and inappropriate safe water storage containers have been inserted in addition to written descriptions. In addition, we have created a water testing result sheet to be given to households that provide water samples to our water quality testing volunteers. These results sheets have pictures which indicate the level of contamination in the sample; the volunteers then circle which level applies to the household and return the sheet with an explanation of the test results.

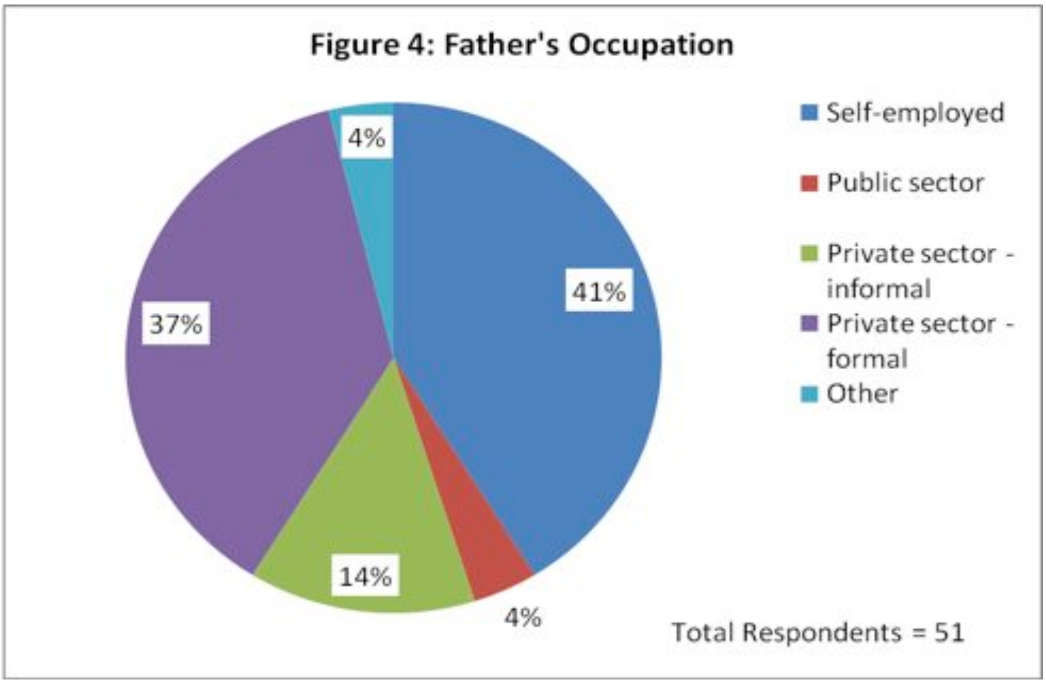
Figure 1 and Figure 2 below show the highest level of education achieved by the mother of the household and the father of the household, respectively. The mothers are slightly more likely than the fathers to have a low level of education, but only 10% of the mothers have any education beyond higher primary school.





Figures 3 and 4 illustrate the mother's and father's occupation, respectively. The results show that 2/3 of mothers are homemakers, indicating households in our target neighborhoods will likely have someone at home during the day; therefore door-to-door marketing may be a fruitful marketing strategy. This also indicates that if the household decides to start treating its drinking water, this job will often be accomplished by the mother of the family; housewives should be one of the main target populations for our point of use (POU) treatment campaign.





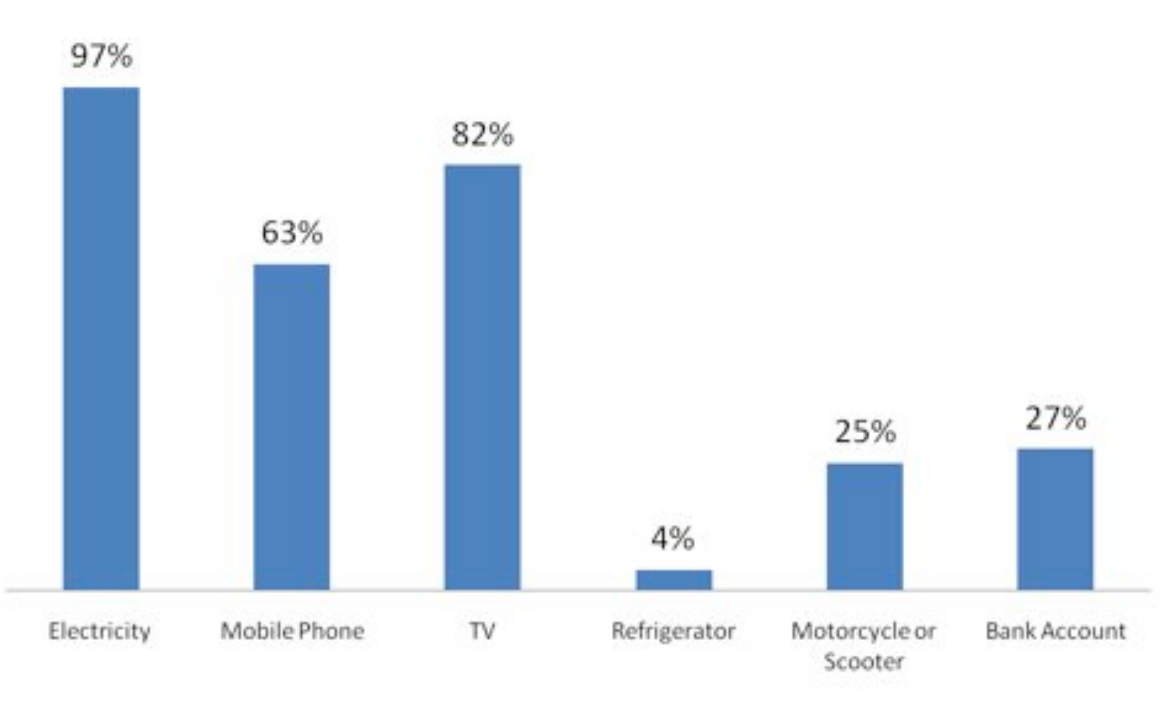
41% of fathers surveyed are self-employed, indicating that these households should be well versed when it comes to simple financial systems, accounting and money management. Therefore they should be able to understand how a micro-credit loan works, if HMS is able to provide loans for those who wish to purchase more expensive water filters. Another 37% are employed in the formal private sector, indicating that these households may have some disposable income available for health purchases.

Economic Characterization

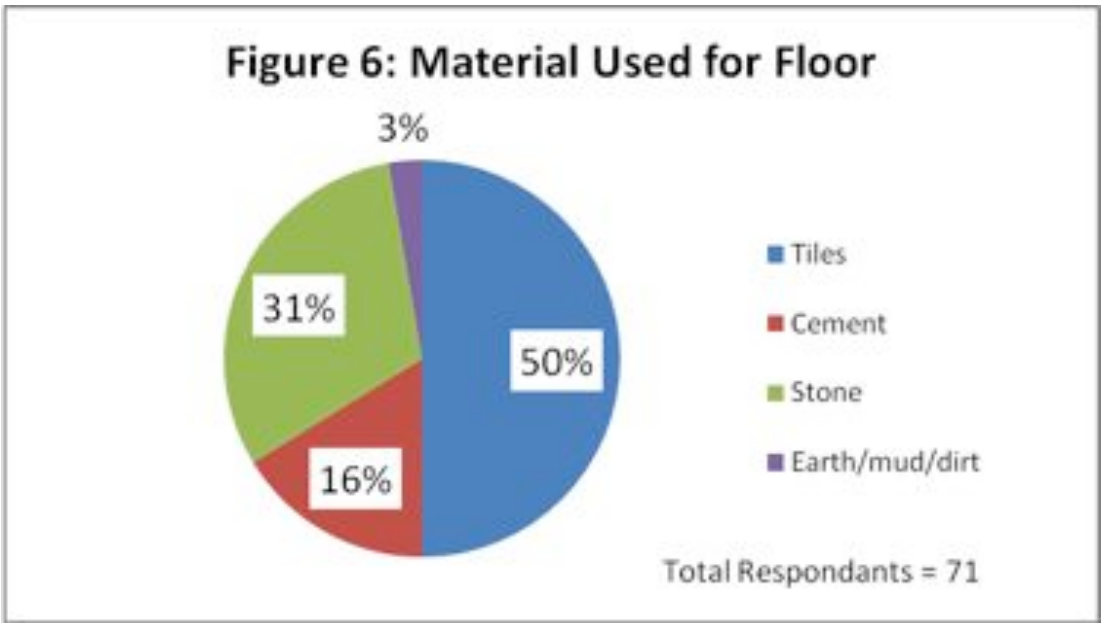
The average income among our households is 4,000 rupees per month, and the median is 3,000 rupees per month – which works out to 100 rupees per day, as many of the households depend on daily wages. The maximum is one household with a monthly income of 15,000 rupees, and the lowest monthly income is 550 rupees.

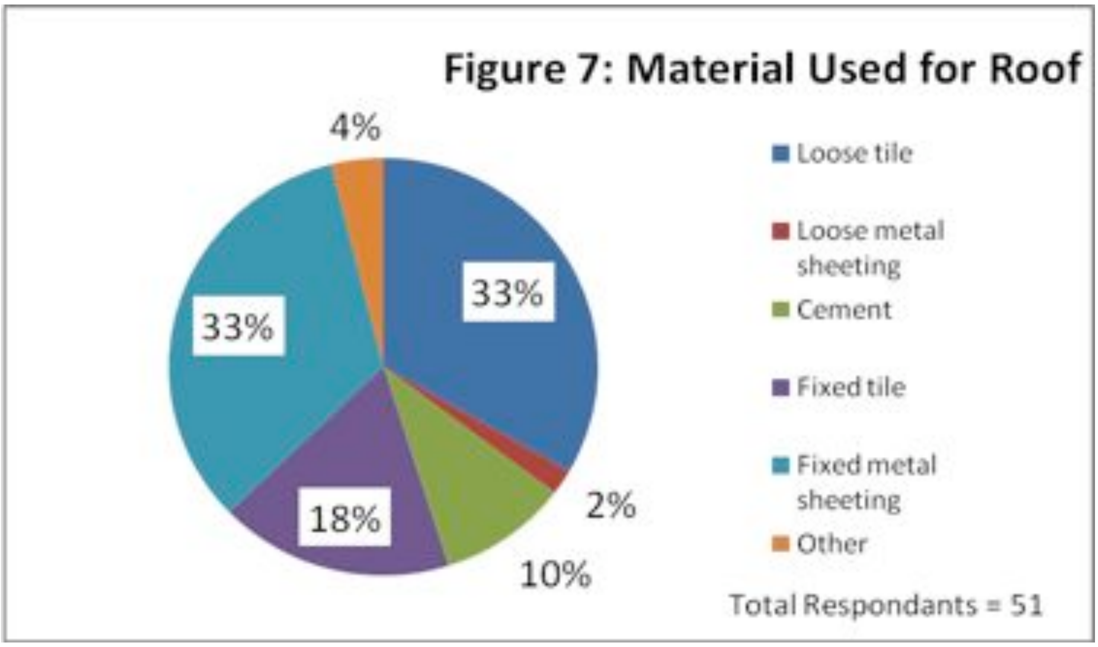
We asked a series of questions about assets that serve as representative indicators of wealth and income. Figure 5 below shows what percentage of our surveyed households own each of the listed items. Of particular importance is the finding that over a quarter of these slum households has a bank account. This indicates that they have enough cash on hand to merit an account, that they are probably saving for their future, and that they may have access to some sort of loans or financing when purchasing large items. This also indicates familiarity with the financial system, indicating that these households would easily understand the functioning of a consumer loan program, should HMS offer one to them.

Figure 5: Representative Assets



Housing is also a good indicator of economic status. The average number of rooms per house is 2.8, and the number of occupants per room ranged from 1/3 to 8, averaging at 2.4 people per room. This indicates a low overall density of the population, compared with large urban slums in India's megacities. At this density there may be room for a safe water storage unit, or even for the construction of a bathroom, unlike many slum households in Mumbai. Figure 6 and Figure 7 show the material used to construct the floors and roofs of the houses, respectively.





73% of those surveyed say that a member of their household owns the land on which their house is located. This is a significant finding for HMS's efforts at increasing sanitation. In general, renters and those with insecure land tenure are much less likely to invest in significant home improvements, such as the construction of a latrine. But a full 34% of households do own the land their house is on but don't own a toilet. These people are a prime target for a private toilet construction project. At the opposite end of the spectrum, only 6%

of households surveyed don’t own the land their house is on and don’t have a private toilet. This indicates there is only a small percentage of people should be targeted through a community toilet sanitation system.

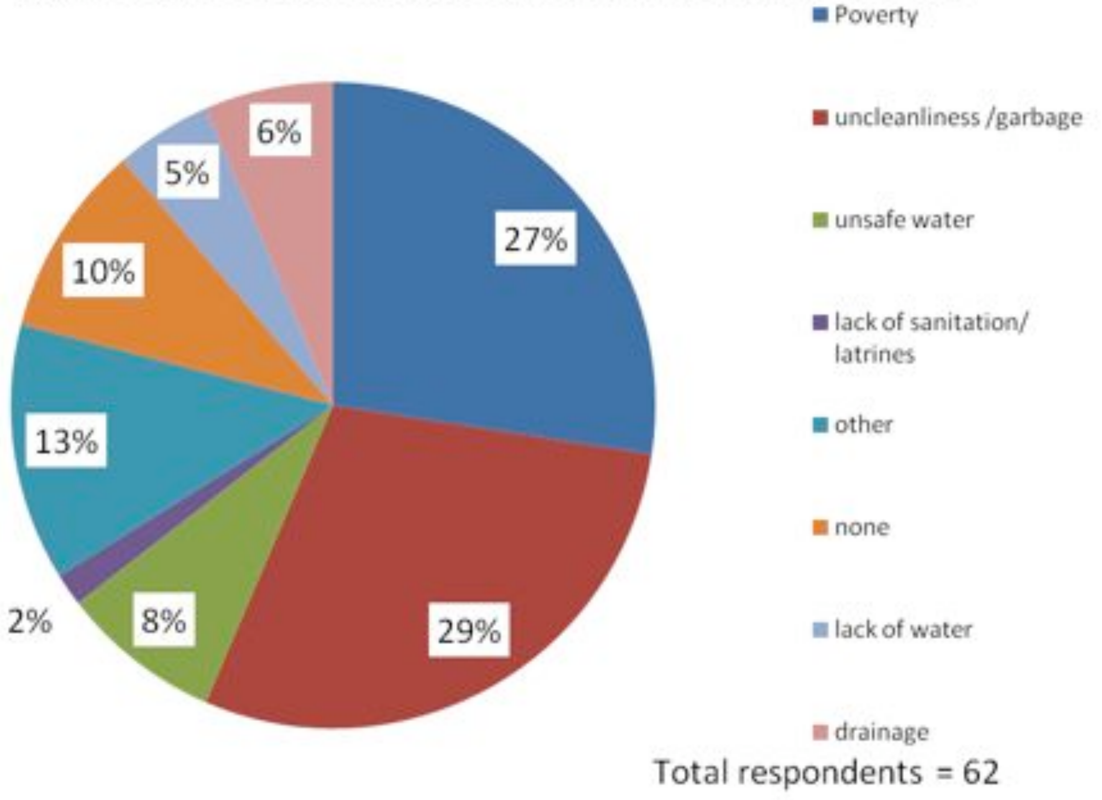
We also asked about who is in charge of making decisions about purchases in the household. Interestingly, the father is responsible for “expensive item” decisions 53% of the time, and the mother only 33% of the time. For daily household items, however, the mother makes the decision 44% of the time and the father only 42% of the time. This indicates that selling large, expensive items like filters is most likely not feasible in a setting in which only women attend, such as at an anganwadi meeting or a women’s group meeting. A less expensive treatment alternative, such as Safewat which costs Rs. 15 per bottle, is much more marketable in situations where only women attend.

Perception and Incidence of Disease

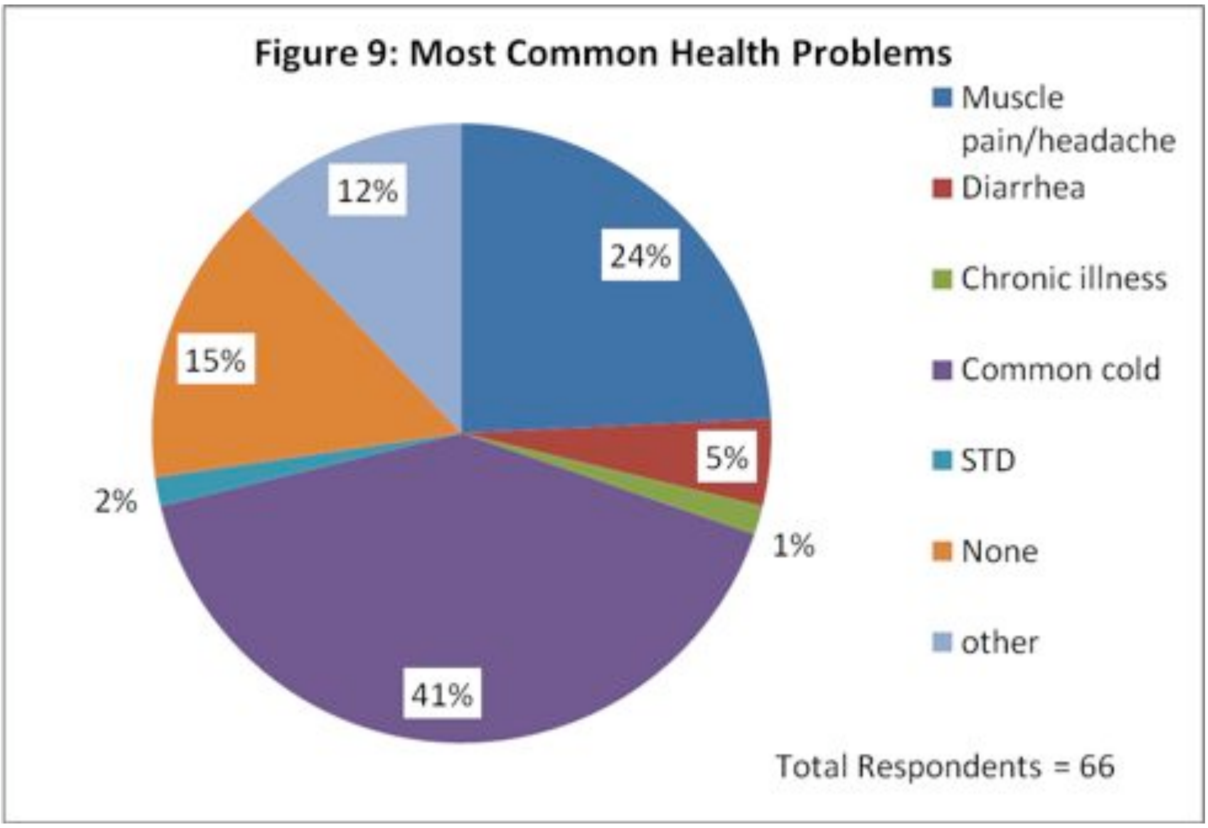
Before creating a targeted health intervention, it is important to ascertain an accurate picture of the communities' perception of disease and its importance relative to other concerns. This is especially critical before attempting to market a new water treatment option because it provides information as to whether awareness campaigns are a necessary component of the success of such a project, versus if people are already aware and simply lack access or resources.

When asked what the most important concern for their community is, 8% of respondents answered unsafe water. This shows some awareness of the problem, though it is not the highest priority concern for the vast majority of those surveyed. As Figure 8 reveals, larger concerns involve cleanliness and garbage, which are also highly correlated with disease incidence and may contribute to the contamination levels in their drinking water. If awareness of this interrelatedness is achieved, then people may be motivated to adopt hygiene habits that tackle both uncleanliness *and* contaminated drinking water.

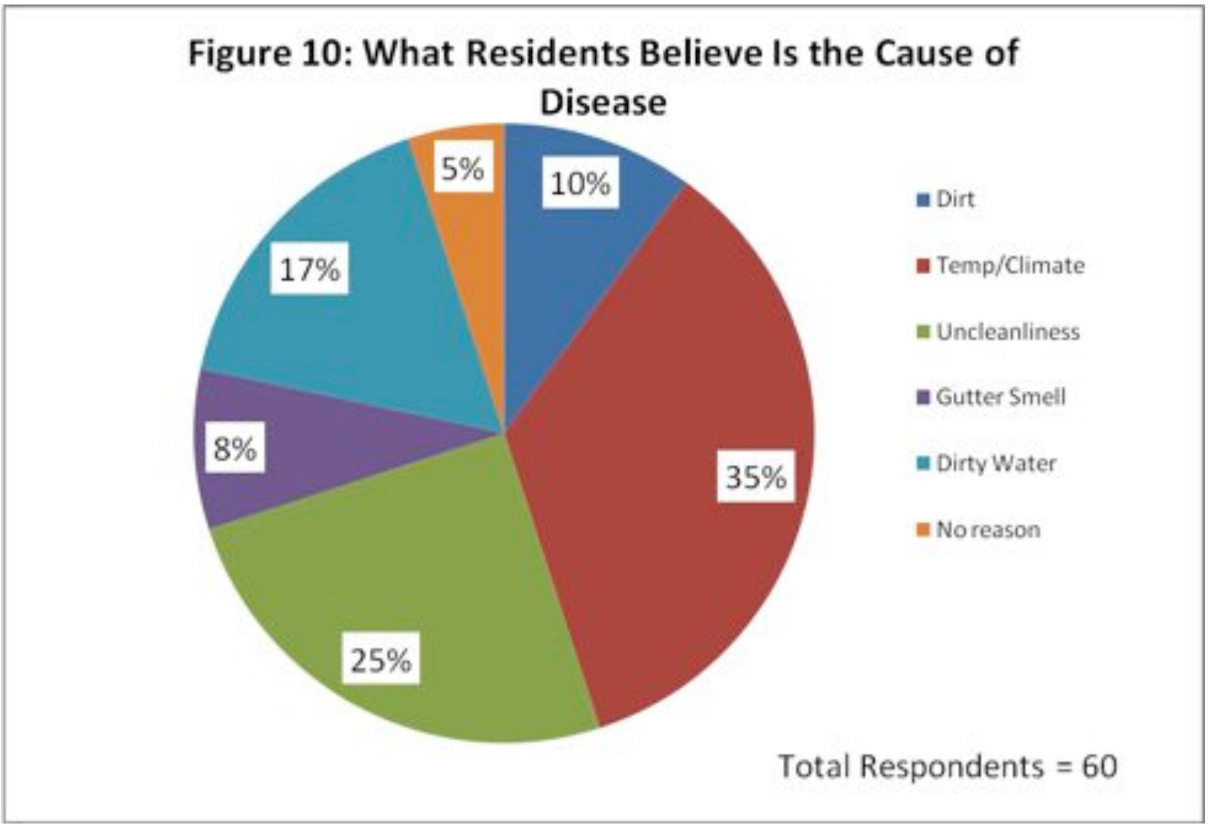
Figure 8: Most Important Concern Stated by Residents



Similarly, only 5% of respondents reported that diarrhea is the most common health concern for their household. However, given the vast range of symptoms produced by water-borne illnesses, it is possible that several of the other health problems are indeed caused by unsafe water. More importantly, the cyclic nature between diarrhea and malnutrition means that people with frequent diarrhea grow up malnourished, which is detrimental to their immune system and in turn makes them more vulnerable to all of the other diseases mentioned as common health problems (see Figure 9). If slum residents are made aware that diarrhea caused by unsafe drinking water increases susceptibility to other diseases and infections by straining the immune system, then we may witness a significant increase in the demand for clean drinking water as a preventative health measure.



Perhaps most significant is the information provided in Figure 10 of people's perceptions of what causes disease and. The number one perceived cause of disease in general is temperature or climate (35% of respondents), which shows a profound lack of education about disease transmission and germ theory. Furthermore, households that believe disease is caused by something uncontrollable like the weather or climate is presumably less inclined to spend money or effort on preventative treatment, such as filtering or treating their drinking water to prevent diarrhea. The relationship between contamination, germs, and disease must be made clear to slum residents in order to empower individuals to prevent diseases. This is the main aim of HMS, as revealed by the wording of our organization's name itself: "Health is in Your Hands."



When asked what causes diarrhea, an even more profound lack of understanding emerges. 70 people answered this question, often giving multiple answers. Of 108 answers given, only 33 were strictly correct. An additional 30 listed causes which could be possible routes of diarrhea transmission, but may not be directly correlated. 5 people simply didn't know what caused diarrhea, and a full 40 answers were recorded which were simply false. This shows that there is a pressing need for a health education program in these areas if the rates of diarrhea are to be reduced. People cannot protect themselves from a disease if they don't understand what causes it.

Table 1: What Residents Believe is the Cause of Diarrhea

Sources of Diarrhea		Possible Routes of Transmission		False Answers	
Stale foods	11	HH uncleanliness	3	Weather	8
Unclean/smelly food	8	Neighborhood uncleanliness	9	Teething	8
Dirty water	13	Street food	14	Overeating	4
Dirty latrines	0	Undigestible food	2	Mosquitoes	6
Not washing hands	0	Government provided food	1	Being in the street	1
Flies	1	Free school food	1	Monsoon	1
Total	33	Total	30	Spicy food	1
				Weak immune system	1
				Gutter smell	1
				Hot food	1
				Eat outside home	1
				Fever	1
				Nausea	1
				Air pollution	1
				Oily foods	1
				Childhood	1
				Evil eye	1
				Common cold	1
				Total	40
				Don't know	5

This lack of knowledge about disease causes and transmission exists despite the fact that 16% of households surveyed had been visited in the past by health workers, and that 45% of these visits included some form of health education. Though the lack of basic disease theory knowledge is alarming, we are encouraged by the fact that health workers have set a precedent of visiting houses individually to give health education, albeit only thus far reaching a small proportion of houses. This information is valuable in finding new avenues for expanding our community outreach and our volunteer programs. One such expansion idea we have developed in response to these survey results is the idea of training nursing college volunteers to go door to door and give information to families about disease transmission and the health effects of drinking unsafe water.

Because diarrhea is one of the leading causes of death in children under age 5 due to severe dehydration, we also wanted to determine how familiar slum residents are with ORS (oral rehydration solution). ORS, when used properly, can drastically reduce the fatality rate of severe diarrheal episodes in children; however, only a third of those surveyed had ever heard of ORS treatment. Of those who had hear of it,79% had used it; a large majority. This implies that if people are made aware of ORS, they are very likely to use it. There is clearly a need for greater knowledge about ORS given the shocking incidence of diarrhea among children in the households surveyed. These households had a total of 156 children under age 15; of those 156 children, 25 of them had diarrhea within the past *7 days* alone (16% of all the children).

Mortality is not the only concern for such a high diarrheal incidence rate.. The consequences of a childhood spent with regular bouts of diarrhea include long-term health concerns related to malnutrition and inadequate absorption of nutrients, which can negatively affect growth and development long after the diarrheal episode itself has ceased. There is reason to believe that moderate or mild diarrhea is much more common than reported by the respondents in this survey, since we also asked for other accompanying symptoms of the diarrhea to ascertain how severe these episodes are and we found that the majority were very severe. 56% of the episodes were accompanied by fever, and 36% were accompanied by vomiting. If the incidence rate of mild cases of diarrhea is much higher than the reported cases, this would have large consequences on the mental and physical development of children living in these slums.

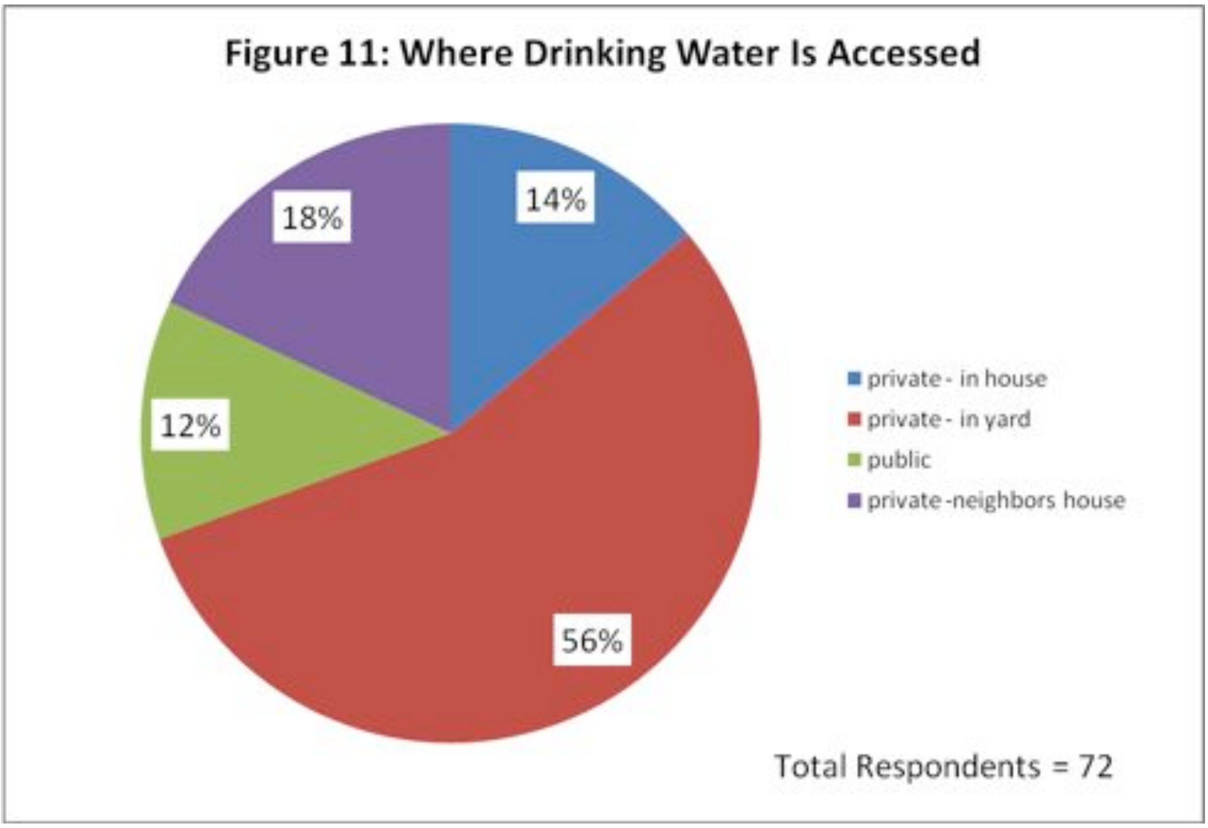
In addition, diarrhea's consequences extend beyond medical concerns: a significant amount of schooling time is lost, and the parents' time and resources are spent taking care of the sick child. The average episode reported by those surveyed was 2.5 days, and school-aged children missed an average of 2.6 days of school recovering at home. Parents spent an average of 3.6 days taking care of child with diarrhea in the past month. Furthermore, the financial burden of dealing with diarrhea for families with limited incomes is considerable. 85% of the respondents said that someone in their household had ever sought medical help for a diarrheal episode. Households reported an average monthly expenditure of Rs. 300 for treating diarrhea – fully 10% of the median household income.

In light of this huge financial burden, if families can be made aware that unsafe water is often the cause of diarrhea, these households may realize the financial efficacy of investing Rs. 500 or less on a filter as a preventative measure. Education and awareness are therefore crucial components of any effective intervention, in order to establish the relationship between diarrhea, healthcare expenditures, and safe drinking water. If households are made to understand this relationship this may generate demand for water treatment products and an increased adoption of healthy hygiene behaviors.

Water Access, Usage, and Treatment

We asked households about their sources and access points for water, distinguishing between water used for drinking and that used for other household purposes such as washing, cleaning, and bathing. Of those surveyed 94% receive their drinking water supply from HDMC. 4% drink piped well water, and only 1% haul their water from a non-HDMC source. None of the surveyed households receive their drinking water supply from delivery truck or from rainwater harvesting.

Figure 11 below shows where this drinking water is accessed. Because 88% of those surveyed receive their drinking water from a private access point, we believe that point of use (POU) water treatment is more suitable for these households than a system of filtration and water distribution at a community scale in which people would have to leave their homes to collect clean water. For those who do have to collect their water either from a public source or from a neighbor's tap, the average time it takes to collect water is only 8 minutes. 72% of those surveyed report that they pay for their drinking water supply, and the average amount paid by those households is 87 rupees per month.



On average, this drinking water is available once every 5.5 days, and it runs for approximately 3 hours on each of these occasions. However, 2/3 of the households reported that water available changes seasonally, often drastically. Several families reported that in the dry summer months, water may only come every 12 to 15 days.

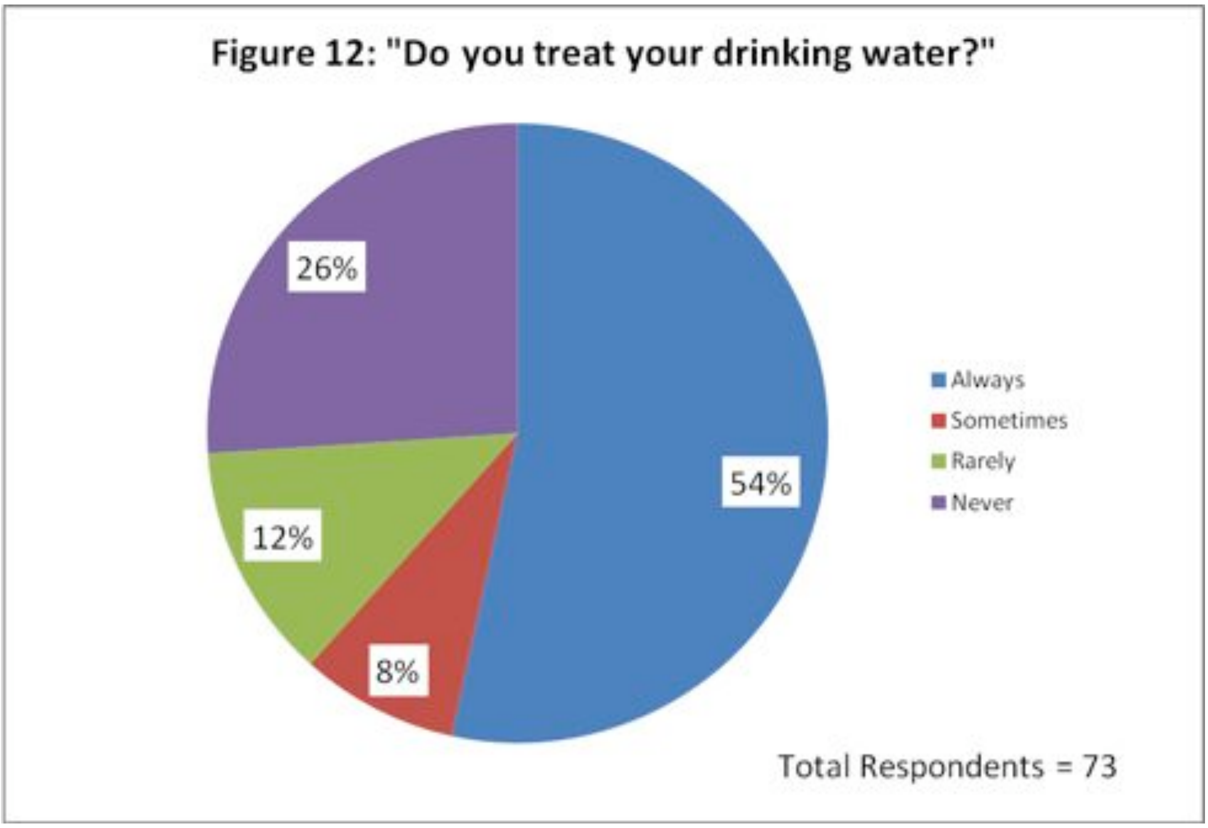
When asked about the smell, taste, and appearance of the drinking water, 71% of respondents replied that everything was fine. Among the other 29%, some mentioned that the water is sometimes red or brown and smells of sewage. A few households specifically mentioned that this discoloration is also seasonal, and tends to be worse during the rainy season. This indicates that the pipes may be damaged and that the water supply becomes contaminated by infiltration of water into the pipes from the surrounding soil, which often includes wastewater contamination. One of the demonstrations in our health education curriculum uses a self-constructed PVC pipe running through a plastic container of "contaminated" (discolored) water to illustrate how this contamination occurs. Though this demonstration was first developed by the HMS Mumbai team, these survey results indicate that the same problem exists in Hubli as well.

For their water used for other purposes (bathing, washing, etc.), 30% of the respondents use water hauled from a well; 18% use piped well water; and the remaining 62% use the same source as their drinking water. In contrast to the drinking water, 82% of the surveyed households receive their non-drinking water from a public tap and they spend an average of 11 minutes to collect it. No one claims to pay for these public water sources. In contrast to the long periods of unavailability of the drinking water. this water supply for other uses is available for about 5.8 days out of every week. This indicates that if these alternative water sources could be treated in the home to be made safe to drink, households could avoid storing their drinking water for days (or up to two weeks), which would decrease the higher contamination levels associated with stored water.

Most commonly (75% of those surveyed), women are responsible for collecting the water when it comes, both for drinking water and non-drinking water. In 38% of households, the men help collect water too; around 20% of households say that children also help out, with an equal percent regardless of the gender of the children.

27% of respondents report that they have ever purchased bottled water. However, only one of these said that she buys bottled water when someone is sick; 80% of the time, bottled water is only bought when traveling. The remaining 15% said that they bought bottled water for some other reason such as a special occasion or for guests.

When asked if they treat their drinking water, 53% of the households responded that they always do, while only 26% never treat their drinking water, as illustrated in Figure 12 below. Though at first glance this seems to be a fairly high percentage of families that already treat their water, it is important to note that this survey question did not specify *effective* treatment of drinking water. As a result, households that kept a sari tied over their tap to filter out large dirt particles claim to always "treat" their water. However, sari or cloth filters are not effective filters for preventing any kind of waterborne illness. This indicates the need for increased awareness and access to low cost water treatment options, such as sodium hypochlorite solution or candle filters.



Of those who claimed to always, sometimes, or rarely treat their water, 25% said they use boiling and 79% said they used a cloth or sari filter. (Percentages do not add to 100% because some households mentioned using more than one treatment method.) Only one respondent used a candle filter.

When those who responded "sometimes", "rarely", or "never" were asked why they do not always treat their water, the dominant response is that they believe there is no need to always treat the water. Clearly this indicates, yet again, a dire need for increased awareness of the level of contamination in water and the myriad consequences of not treating drinking water. Figure 13 summarizes the rest of the responses. Three respondents – nearly 10% -- admit that the reason they do not treat their water is because they do not know how. The Water Treatment Options pamphlets we created and began distributing in June 2009 address this segment of the population by providing information on what options exist, how effective they are, and where they can be purchased. Another three respondents claim that treating water is too expensive; this shows that there is a portion of the population that has immediate demand for a cheaper alternative – such as Safewat, which we are now making available in Hubli – without necessarily requiring awareness about the need to treat water.

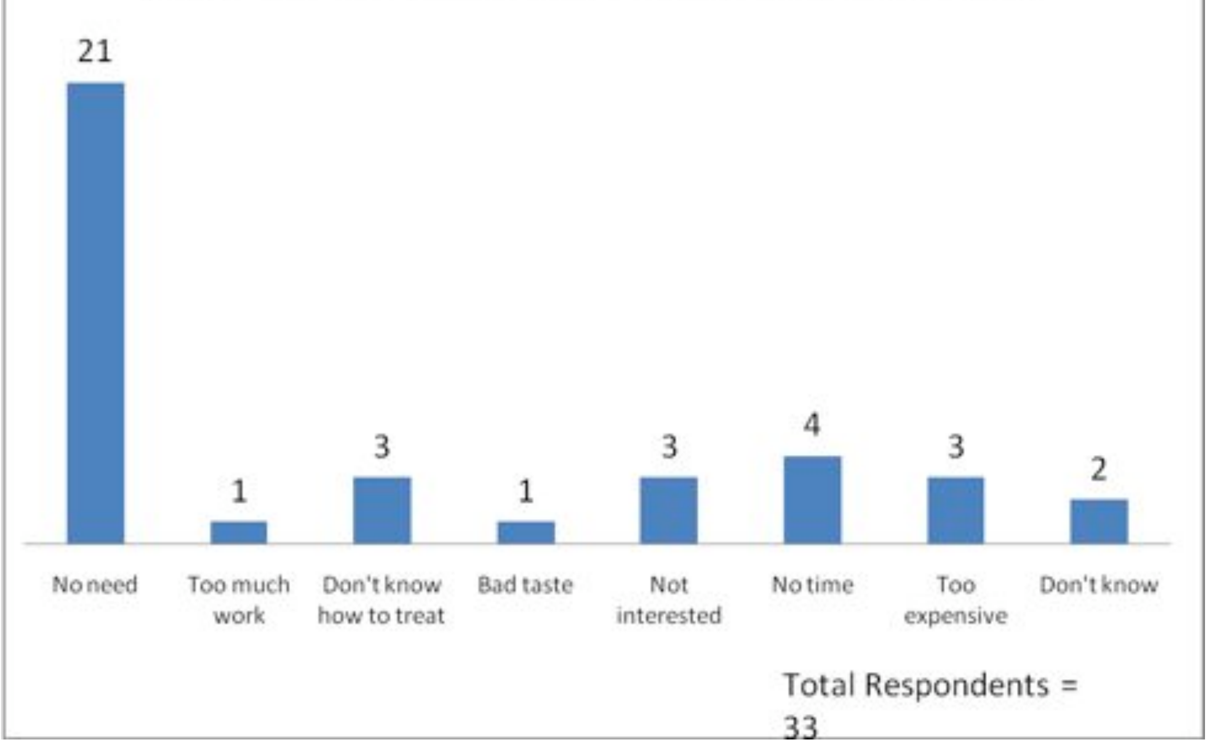


Figure 13: "Why don't you treat your drinking water?"

Of those that only sometimes or rarely treat their drinking water, 79% do so only when someone is sick or when the doctor advises them to. The remaining 21% choose to treat their water only when it is visibly dirty, though this is almost always only with a cloth or sari filter which does not remove any of the bacteria that would presumably be in the water if it indeed has been contaminated by sewage in the pipes.

Even among those who believe there is no need to always treat water, we found that they often do not know of any methods for treating it even if they were interested. When those who did not always treat their water were asked which water treatment methods they knew of, 13% said cloth filters (not an effective option), 13% said candle filters (somewhat effective – they remove parasites and some bacteria), 48% said boiling and 8% mentioned a commercial filter such as the Pure-it or Aquaguard (both of which are effective at removing all pathogens to acceptable levels). However, fully 39% replied that they did not know of any water treatment options. Therefore, even merely familiarizing people with the existence of these and other options is a significant step in making water treatment a viable option for households.

When we asked where those who do treat their water learned how to do it, most respondents said that they figured it out themselves, knew it from family tradition, or learned it from a friend or neighbor. Two households mentioned that they began tying a cloth filter on their tap after finding insects in their water. Several households said that they learned these methods from either a doctor or a health worker. Others mentioned that they had observed it being done in their neighborhood so they began doing it too. These responses indicate two things: first, that members of the community are receptive to changing their habits if advised to do so by someone with medical authority; and secondly, that the benefit of introducing filtration options to the community has the potential to create demand even in households that have not been in direct contact with an HMS volunteer, since information is seen to spread within local social networks and by direct observation.

In the majority of cases (80% of households who treat water), it is the mother who decides when and how to treat the water. Therefore, as mentioned previously, the most effective strategies for encouraging adoption of treatment methods must involve targeting women and especially mothers with young children.

Of the 51 respondents who claim to ever treat their water, 10% spent money in the last month on these treatment methods. The average amount spent among these families is 41 rupees in the last month. By contrast, the sodium hypochlorite solution Safewat costs only 15 rupees per bottle, which will last at least one month.

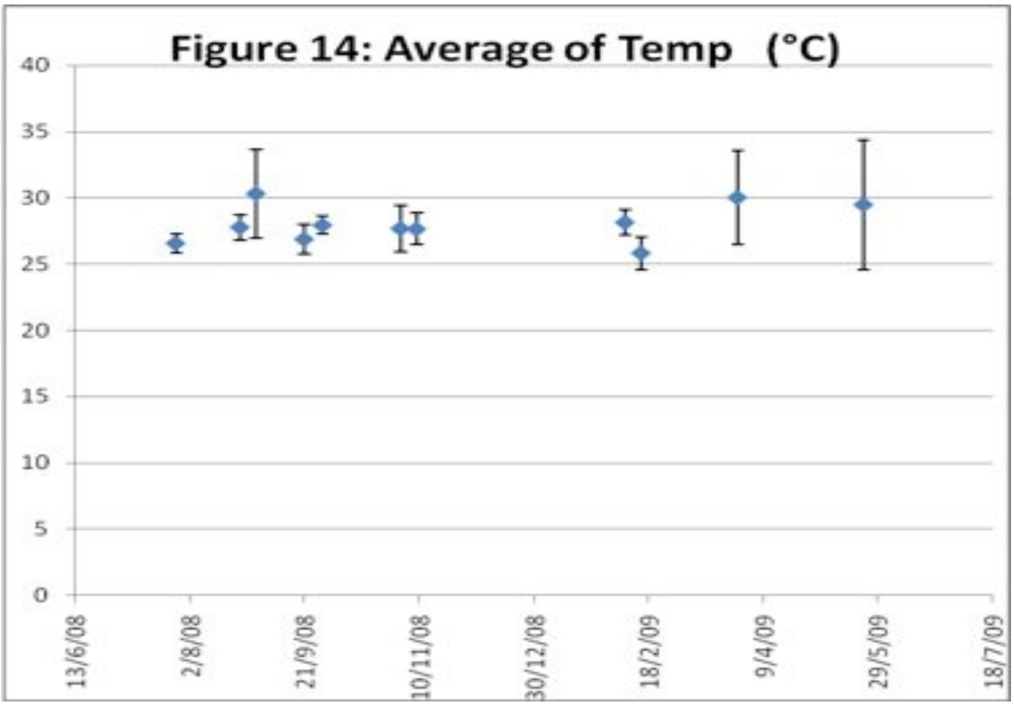
The other main source of drinking water contamination is from improper handling or storage in the home. The surveyed households' drinking water storage containers were observed directly during the survey to look for safe water storage vessel characteristics. 96% of the households have a separate storage vessel for their drinking water to separate it from the water used for the rest of their activities. 98% of these containers were covered, though often only loosely with a plate or another container instead of with a tightly sealed lid that would prevent children from accessing the water with their hands. Only one container was observed to have a mouth opening small enough to prevent hands from reaching into the container; the other 98% of the containers had mouths wide enough to allow contamination by dipping hands or cups. 78% of the containers were kept on an elevated platform, while the remaining 22% rested directly on the floor.

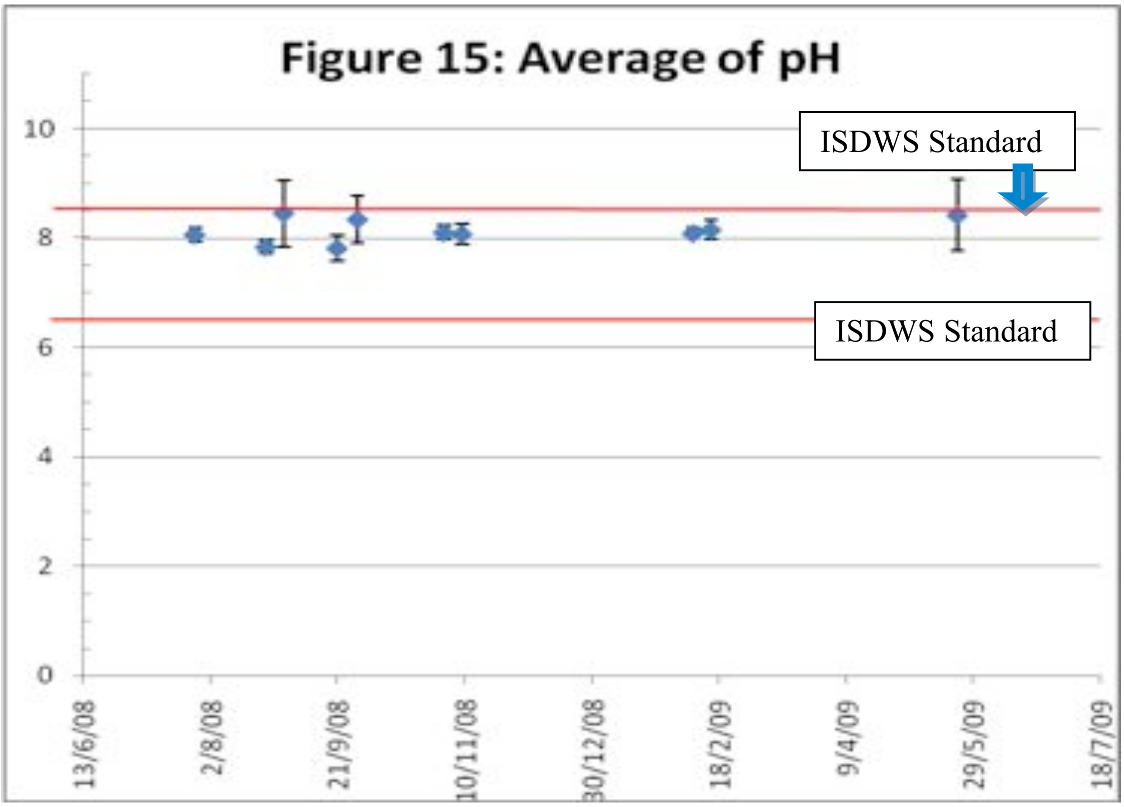
We then asked the interviewee to demonstrate for us how they typically retrieve drinking water from their storage container and we observed their technique. None of the 64 people who agreed to demonstrate used any of the safe water retrieval methods (using a ladle, pouring, or a spigot or tap on the storage container). 33% dipped into the container with a cup that had been hanging up; 58% dipped with a cup that had been resting on an elevated surface; and the remaining 9% dipped with a cup that had been resting directly on the floor. In 70% of these cases, not only the cup but also the interviewee's fingers entered the water in the storage container.

Water Quality Analysis

In addition to the household needs assessment survey, HMS Water Quality Testing volunteers conducted monthly water quality tests for 7 months on 30 randomly selected households in the neighborhoods of Old Hubli, Anand Nagar, and Heggeri. Of this regular testing, 17 houses in Anand Nagar and Heggeri yielded good quality results. Households were asked to give volunteers samples of their drinking water, almost always taken from stored water containers. In addition, a public access water tank in Anand Nagar was tested at the same time. This water tank uses borewell water as its source, is accessible to the public at no cost, and is maintained by the HDMC. Samples were tested for pH, temperature, total dissolved solids, total chlorine, *E. coli* and total coliform. Households were also asked when they last received piped water, in order to estimate how long their drinking water had been stored before sampling.

In general, temperature was at acceptable levels (see Figure 14). Data for pH was slightly higher than is preferred; 14% of samples were above the The Indian Standard Drinking Water Specification (ISDWS) of 8.5; the maximum found was 9.63, which is quite alkaline for drinking water. All samples were above the lower limit of 6.5 (see Figure 15).





Household survey results were overwhelmingly upheld by the water quality data. Contamination of drinking water by total coliform was found in all household and water tank samples. ISDWS states that in a set of samples, no more than 5% of the samples should have any total coliform, and of those samples none should contain more than 10 Colony Forming Units per 100 ml (CFUs/100 ml). Only 2 samples had less than 10 CFUs/100 ml, out of 84 samples, and none had zero. The maximum number of total coliform found was 47,200 CFUs/100 ml. This proves that contamination is occurring, at unacceptable levels, and that whatever treatment is occurring is completely ineffective. It is not clear from this data set whether the contamination occurred in the pipe network during storage in the home. HMS suspects that both are the case. Shown below are all household data found for total coliform (Figure 16) and all household data found with total coliform less than 1000 CFUs/100 ml (Figure 17); the second graph is shown in order to display the magnitude with which the ISDWS is violated. The water tank was found to have an average total coliform concentration of 1400 CFUs/100 ml, with a range between 40 and 5400.

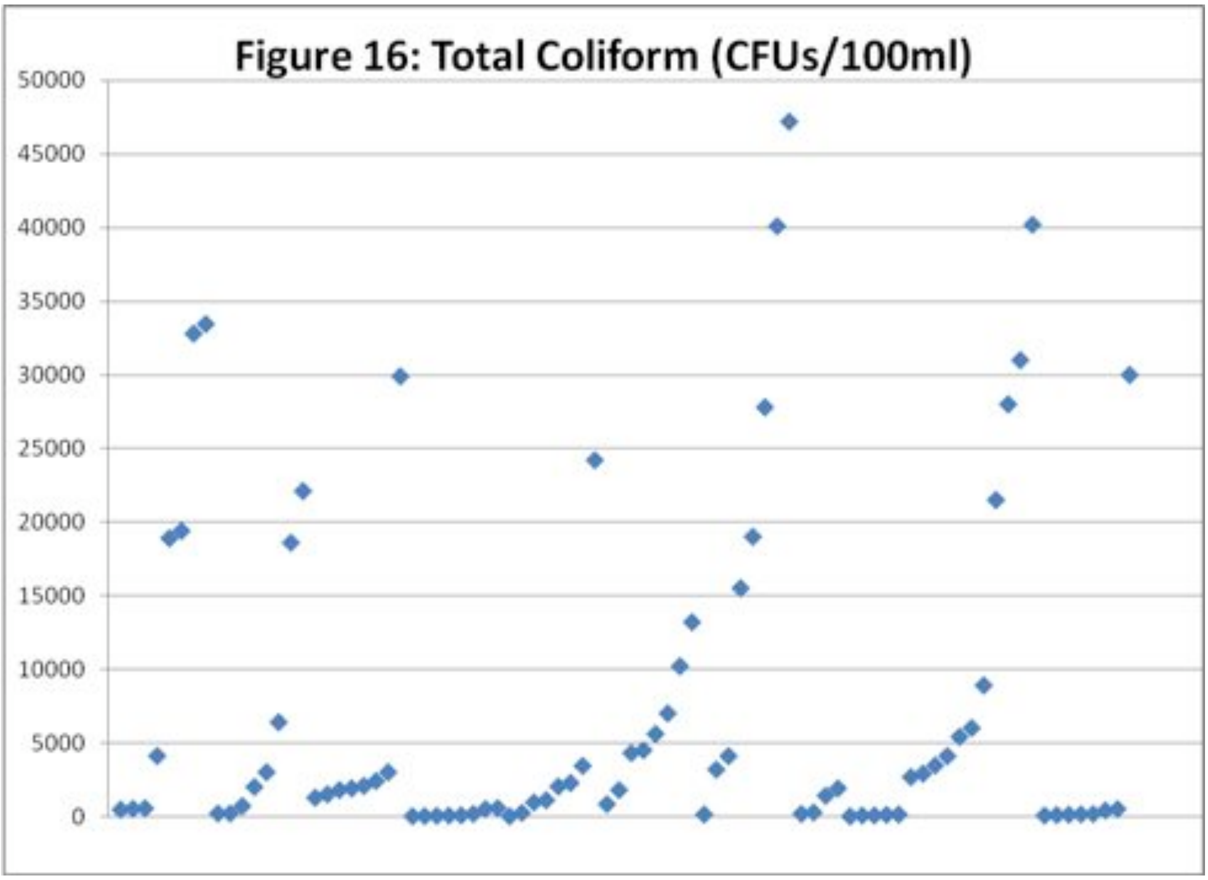


Figure 16: Total Coliform (CFUs/100ml)
50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0

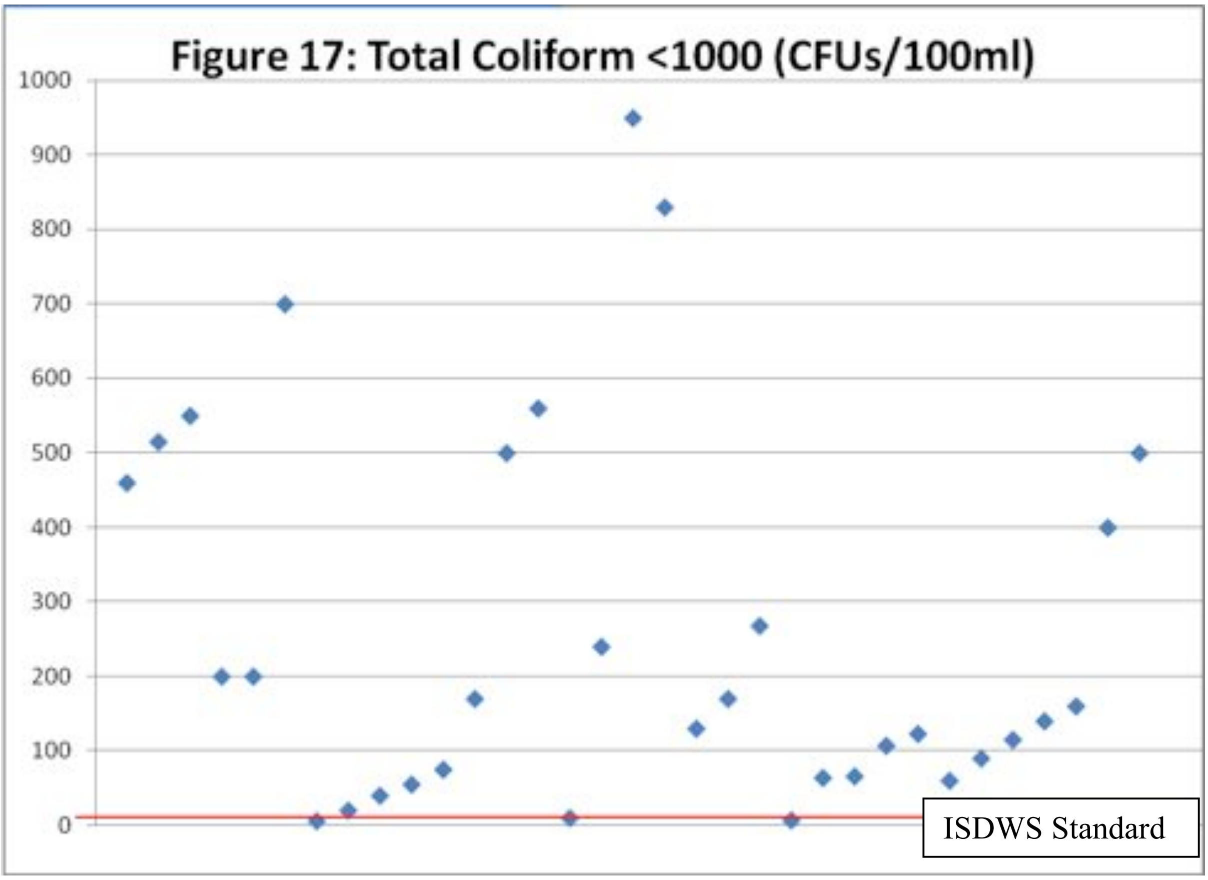
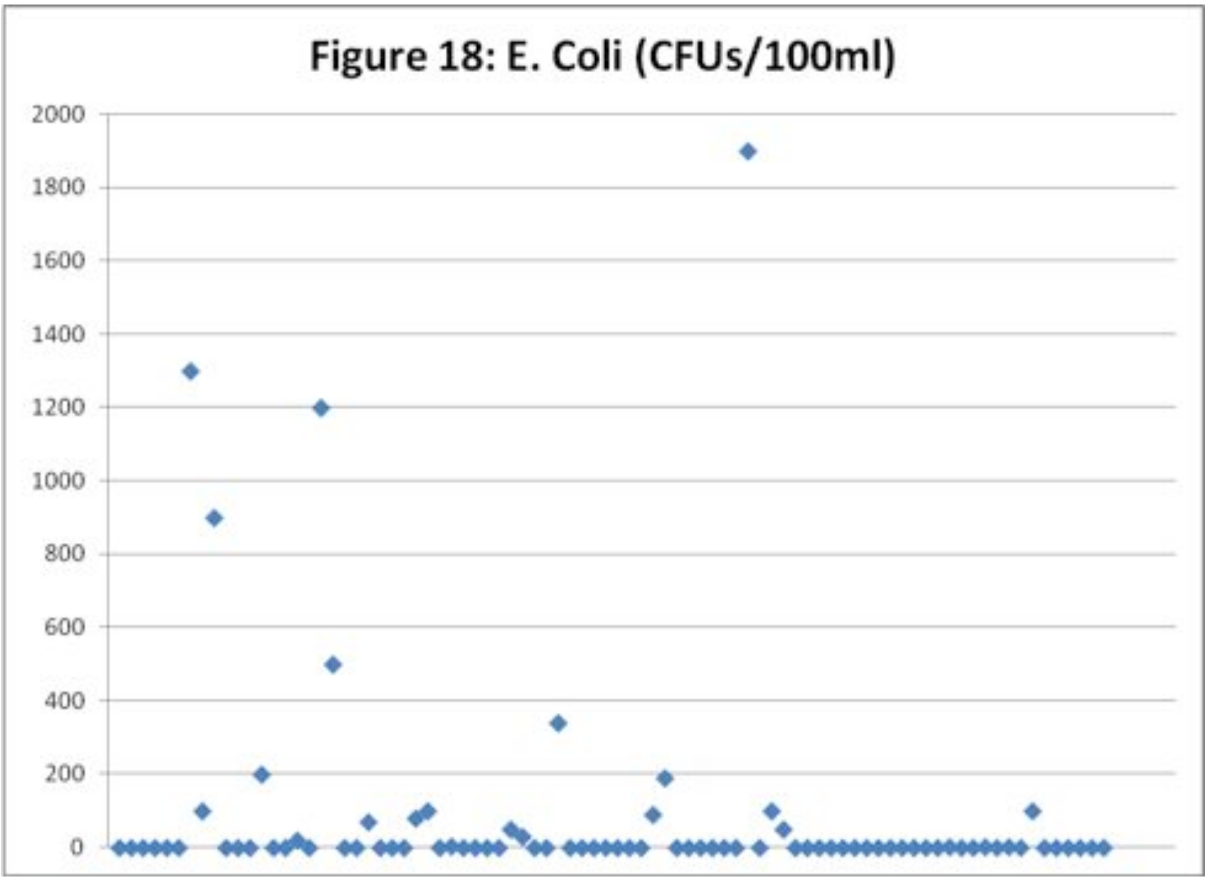
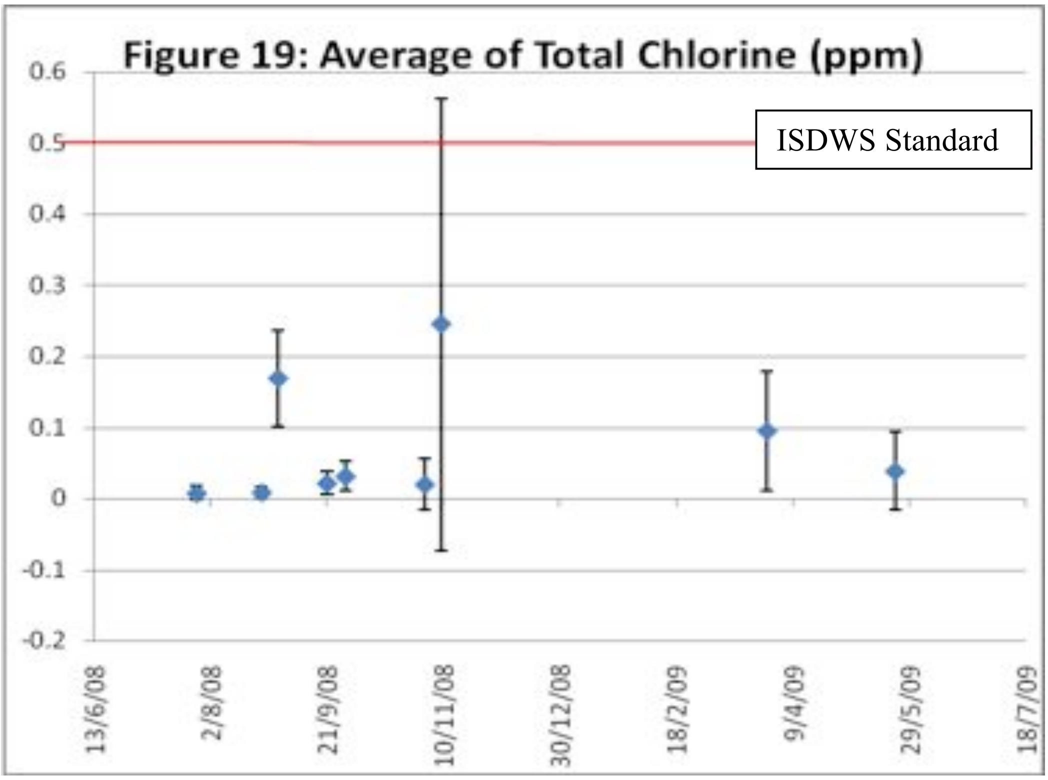


Figure 17: Total Coliform <1000 (CFUs/100ml)
1000
900
800
700
600
500
400
300
200
100
0
ISDWS Standard

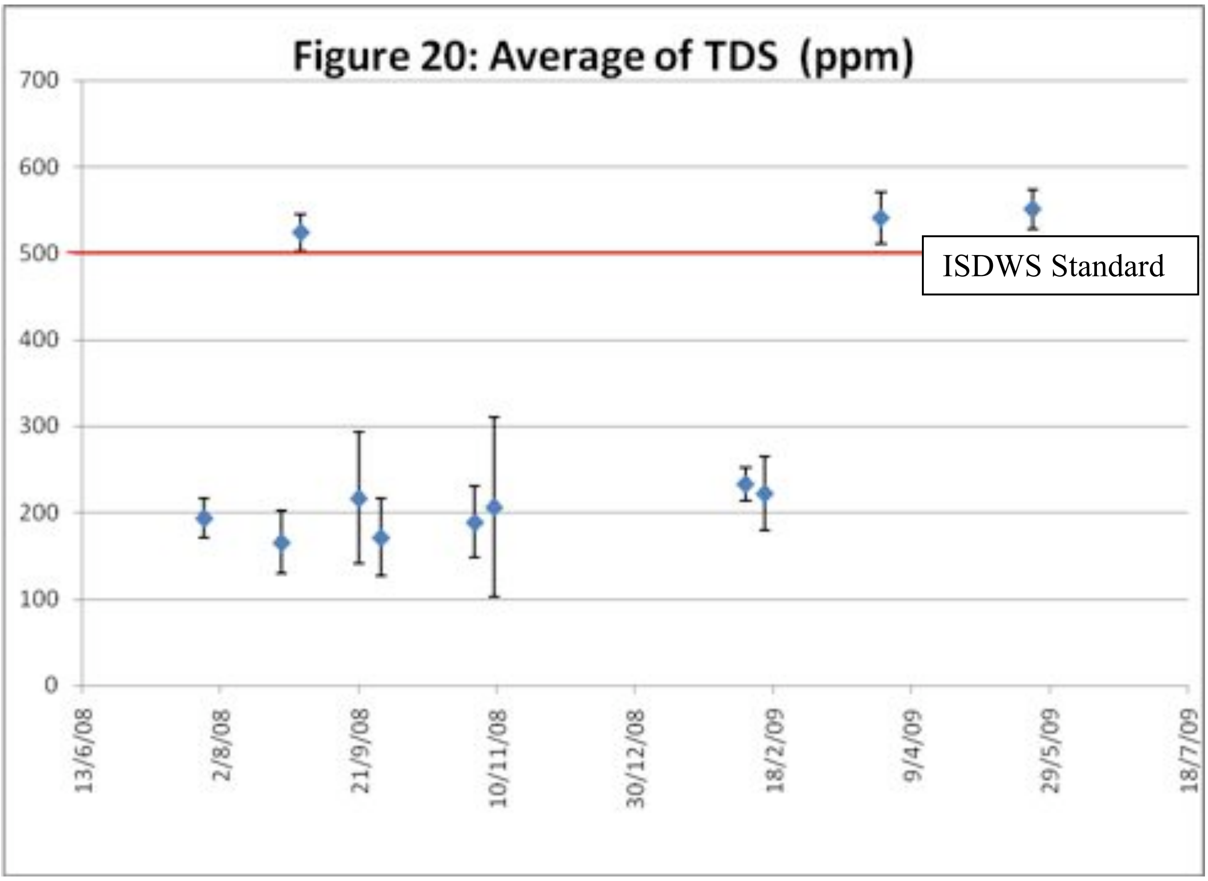
Since *E. coli* is a subset of total coliform, violation of the total coliform standard renders a sample bacteriologically unsafe for consumption. Yet it is good to review the *E. coli* concentration as well, since it shows the clear presence of fecal contamination. Water known to be contaminated with feces is extremely likely to contain waterborne pathogens and should not be consumed. The presence of total coliform, on the other hand demonstrates bacteriological contamination, but that may not necessarily be due to the presence of feces. 27% of household samples tested positive for *E. coli*, indicating that residents in these areas have at least a 1 in 4 chance of consuming fecally contaminated water (see Figure 18). The maximum concentration of *E. coli* was 1900 CFUs/100 ml. 2 out of 5 water tank samples were found to contain *E. coli* but the maximum concentration found there was only 100 CFUs/100ml. This may indicate that the majority of *E. coli* contamination occurs within the home, but more testing is needed to be sure.



The ISDWS states that drinking water which needs to be free of viruses should have a residual chlorine at or above 0.5 ppm. HMS tested for total chlorine, which is roughly a combination of residual chlorine, combined chlorine and chloramines, and is therefore always larger than the residual chlorine concentration. Despite this, the total chlorine concentration was below the level required by the ISDWS for 99% of household samples. The fact that chlorine is present at all indicates that some of the chlorine added by HDMC does make it into the home, but at insufficient concentrations. It is possible that the concentration is sufficient at the tap but not after storage in the home, although this is unlikely because 9 of the samples were taken on the same day that HDMC water was delivered and only one met the ISDWS for chlorine residual. The data on total chlorine show three things: 1) the water is unfit for consumption; 2) the chlorine added by HDMC does not remain at sufficient concentration after storage in the home, and likely does not even remain at a sufficient concentration at the point of access and 3) it shows that residents are not treating their water with sodium hypochlorite, which is corroborated by the survey responses (see Figure 19). Surprisingly, HMS volunteers found chlorine present at the water tank as well. Although only 1 out of 5 samples had a total chlorine concentration above the standard for residual chlorine, all samples contained some amount of total chlorine. This indicates regular, but insufficient, chlorine dosing by the HDMC.



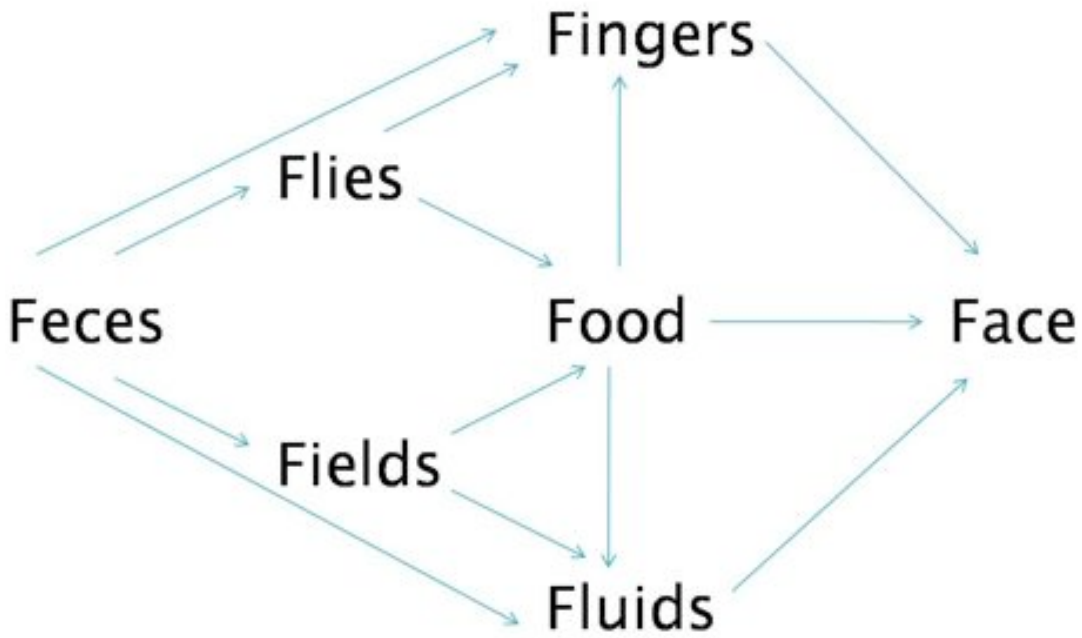
The ISDWS recommends that total dissolved solids (TDS) be less than 500 ppm, in order to remain palatable. 24% of samples were above this recommended limit, but not by much; the maximum TDS found was 592 ppm. This level of TDS might have a poor taste, but it is not considered a hazard to human health. The drinking water found in people's homes was slightly above this standard on three sample dates, but it is noteworthy that almost all samples taken on those dates were above the standard and significantly above the concentrations found on all other dates (see Figure 20). Although this concentration of TDS is not in and of itself dangerous, it shows that the HDMC water delivered on those dates must have been mixed with more brakish water, since HDMC water is usually <200, as shown by the TDS concentrations found on the other sampling dates. This mixing is cause for concern. It is likely either due to residents mixing HDMC water with borewell water, or from infiltration in the pipe network. It is further noteworthy that 2 of the dates with high TDS occurred during the dry season in Hubli. This may point to mixing of HDMC water with borewell water in the home, since some residents reported receiving HDMC water only once every 12-15 days during the dry season, necessitating some supplementation of their drinking water supply. This is supported by the average TDS found at the water tank; at 402 ppm, borewell water, at least in Anand Nagar, is twice that typically found in HDMC water.



Hygiene and Sanitation

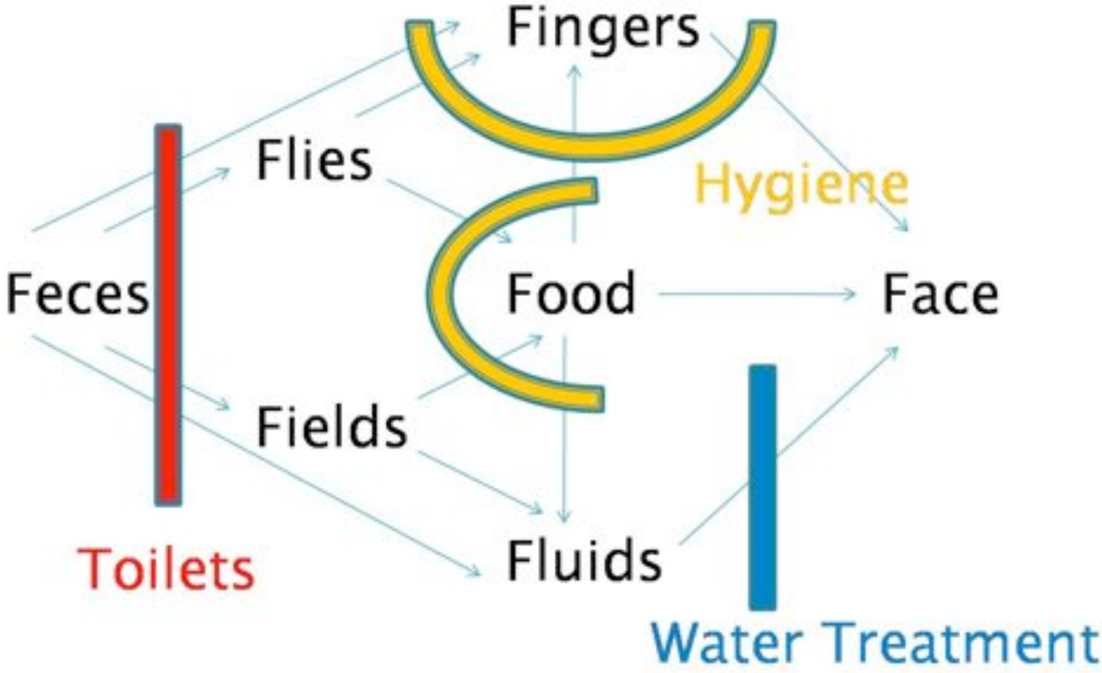
Water borne illness is not always contracted through contaminated drinking water. The term 'water borne' in general refers to diseases caused by pathogenic organisms which target the gastrointestinal tract. These organisms include viruses, bacteria, protozoan parasites and helminthes. They are contracted through the ingestion of small amounts of the fecal matter of a diseased individual. Ingestion can occur through several different pathways, as shown in Figure 21, collectively known as the 'fecal oral route'.

Figure 21: The Fecal-Oral Route



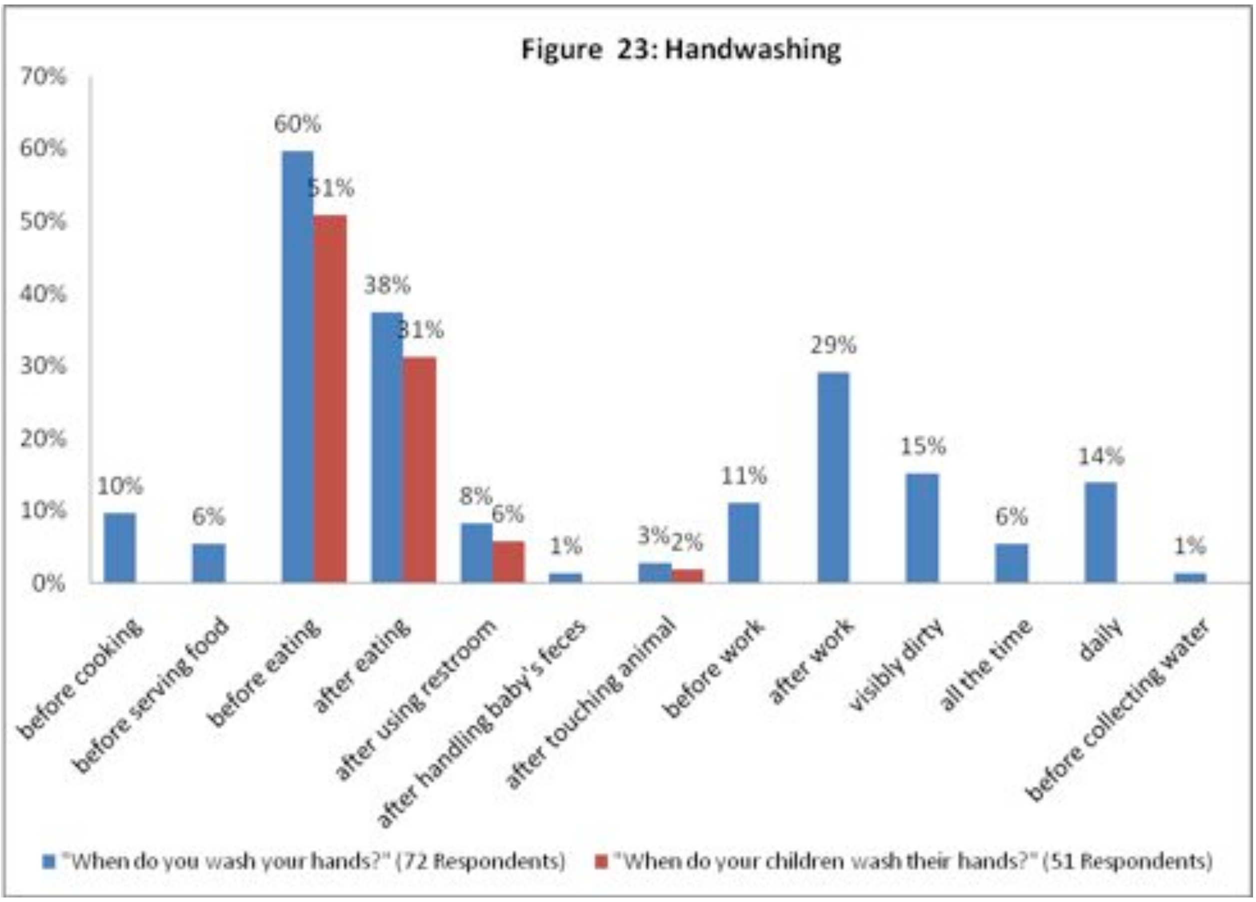
Reducing the spread of water borne illness can be done by blocking any one of the possible pathways of contamination. Drinking clean water, which has been treated for the removal of pathogenic organisms, is one important way of preventing disease. Other methods include preventing pathogenic organisms from entering the environment, through the universal use of toilets, and preventing the contamination of hands and food, through proper hygiene. Hygiene here refers to a broad sense of the term; hand washing, food cleaning and thorough cooking of food are included, as well as proper collection and disposal of solid waste and the elimination of disease vectors such as flies and rats (see Figure 22).

Figure 22: Interventions to Break the Fecal-Oral Route



Increased hand-washing with soap, in particular, has been found to have a large effect on the rate diarrheal incidence as well as the rate of respiratory disease.[3] It is therefore comforting that 94% of those surveyed state that they regularly use soap when they wash their hands. This shows residents are aware of the importance of soap usage. However, the observation portion of the needs assessment survey reveals that there is a significant disconnect between knowledge of proper hygiene behaviors and actual practice of these behaviors. Residents were asked to show the surveyor their private toilet, if they had one, but the surveyor did not state what they were looking for. Of the bathrooms directly observed by the surveyor, only 14% had soap nearby and only 58% had water accessible nearby. It is possible that soap and water were simply out of sight in some of the houses, but it is likely that many simply did not have soap available near the bathroom.

Unfortunately, those surveyed were not often able to correctly tell HMS when it is important to wash their hands. Hand-washing should be done, at a minimum, before eating, after using the restroom, after handling babies feces, after touching animals, before serving food and before cooking. Although a majority reported washing before eating (60%), a small number of respondents reported hand-washing during the other times when it is necessitated: only 8% after using the restroom, 1% after handling children's feces, 3% after touching animals, 8% before serving food and 10% before cooking. Similar results were found for the hand-washing behavior of children (see Figure 23). This shows a great need for promoting hand-washing in order to prevent the transmission of diarrheal disease. In particular, these answers and the previously mentioned observations point to the need for increased hand washing after bathroom usage. The promotion of soap usage should be included in this campaign for completeness, although its widespread use does imply it is of a lower priority than communicating to residents the times when hand-washing should be performed.

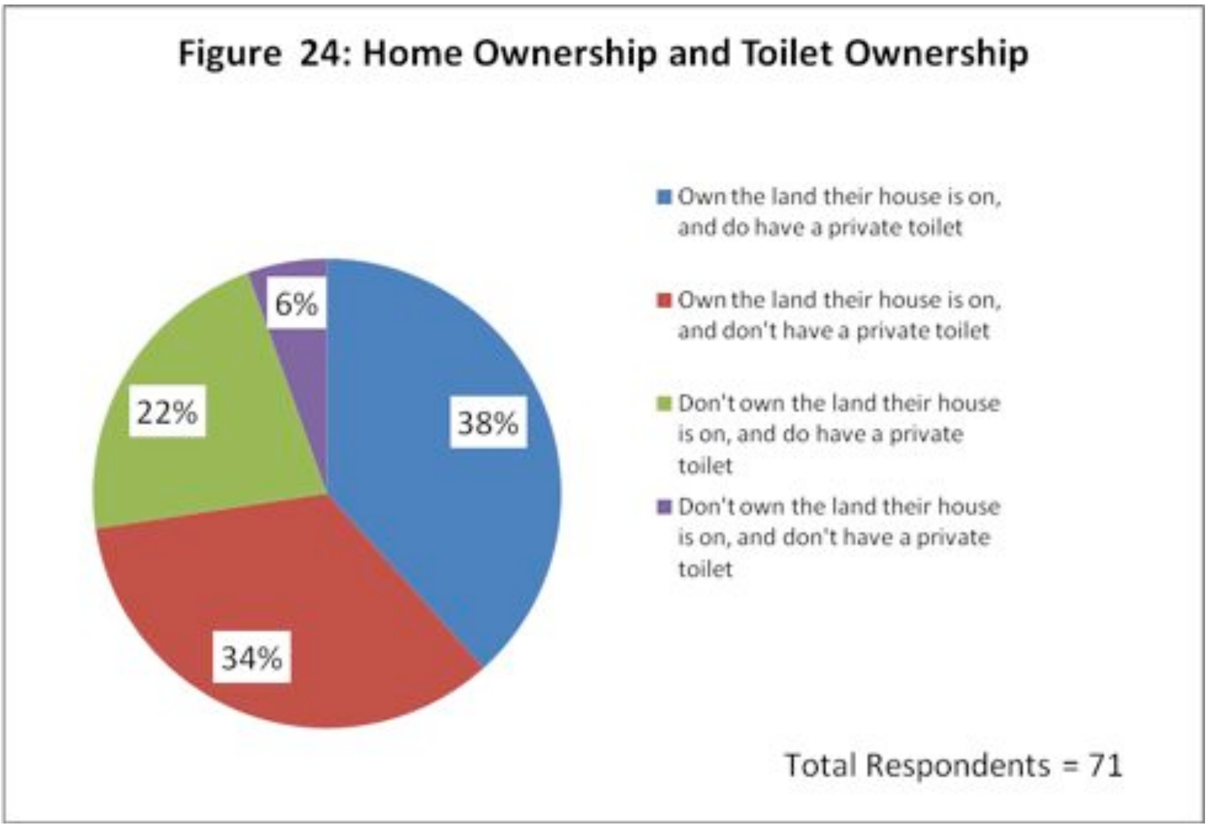


Preventing contamination of the inhabited environment is also a crucial step towards preventing disease. This requires universal toilet access and regular usage. The toilets must collect the feces and isolate them from human contact until they have been disinfected. Disinfection can occur on site in a compost toilet or septic tank, for example. Otherwise the untreated waste is carried to a centralized location for disinfection. If disinfection occurs on site, re-use of the nutrients found in both the feces and urine can occur either at the same location or somewhere nearby.

Wastewater containing human feces is known as blackwater. Transporting untreated blackwater to a location away from human inhabitation for direct discharge can have serious detrimental effects on human settlement and ecosystems lying downstream. In an urban environment, such as Hubli, discharging untreated blackwater in local streams can have detrimental effects on upstream residents as well: populations, and therefore disease, can travel upstream. Likewise, untreated blackwater is used to irrigate vegetable crops downstream, which are then sold to upstream residents for consumption. In Hubli, vegetables sold in the local markets are often contaminated in this manner.[4]

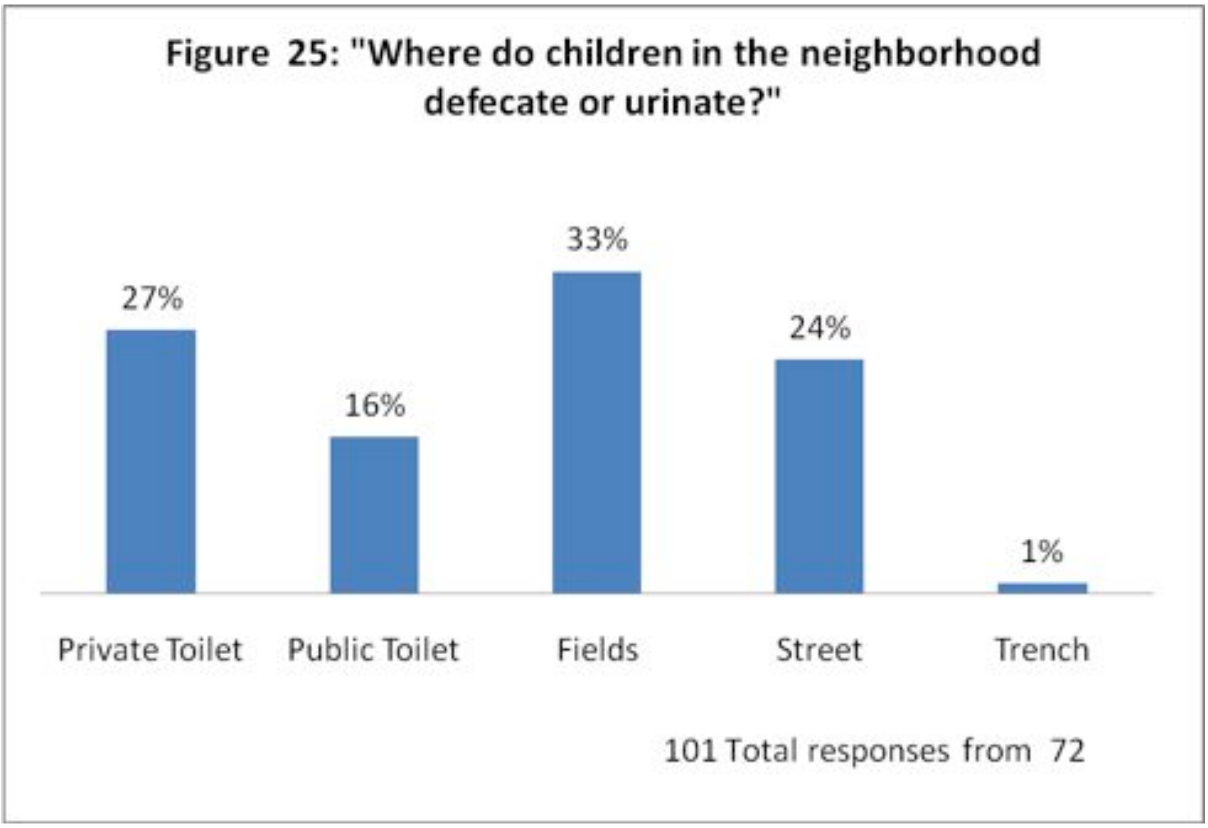
In Hubli, untreated blackwater is often discharged into uncovered stormwater drains; 67% of those residents reporting ownership of a private toilet discharged untreated blackwater into open channels while only 10% discharge to a covered sewer and 2% to a septic tank. In the case of an open channel, the blackwater is not isolated from human contact; it is merely transported outside of the house. In this case animals, flies and humans can come in direct contact with the raw feces, spreading contamination to local residents. Often the channels do not drain properly, either due to blockages of trash deposited by local residents or due to inadequate grading. In these cases the open sewers are very likely a major source of water borne disease, either through direct contact or through infiltration into the drinking water pipe network.

89% of residents surveyed reported having access to a toilet; therefore it is implied that 11% of those surveyed practice open defecation. Since this is a taboo behavior, it is likely that the actual figure may be higher, since the desire to appear a certain way in front of the surveyor may have introduced bias. In addition, having access to a toilet does not necessarily mean that it is used consistently or at all. Subsequent anecdotal conversations with community members reveal that even when access to toilets is available, they are often underutilized either because of expense (in the case of public toilets) or because of uncleanliness. Of the residents who stated they have access to a toilet, 68% had access to a private toilet, while 35% had access to a public toilet (see Figure 24). Some residents reported access to both, indicating there may be some people who use both types of toilets. 76% of those using a public toilet reported payment of a fee, typically 1-2 rupees per use.



The number of families which share the local public toilet was hard to estimate for most people. The range of numbers given was large, ranging from 35 to over 400, but in general most respondents agreed that it was larger than 150 families. All of these public toilets were reported to be maintained by the Hubli-Dharwad Municipal Corporation (HDMC). Approximately half of those who used a public toilet reported that these toilets were clean. There were also 6 people who reported using a toilet that was shared between 2-5 families. One family reported paying 70 rupees per month for access to their shared toilet.

Even if a family has access to a toilet, this does not necessarily mean that all members of the family always use it. Since it may be embarrassing for someone to admit to open defecation, participants were not directly asked where they or their children defecate. Instead, they were asked where children in the neighborhood defecated, in order to make the question less personal. Framed in this way, open defecation looks far more wide-spread than 11%. Since children in the neighborhood may defecate and urinate in more than one location, respondents were allowed to give more than one answer; Figure 25 gives the percentage of the total number of responses. This indicates that, at least among children, open defecation is more common than toilet usage.



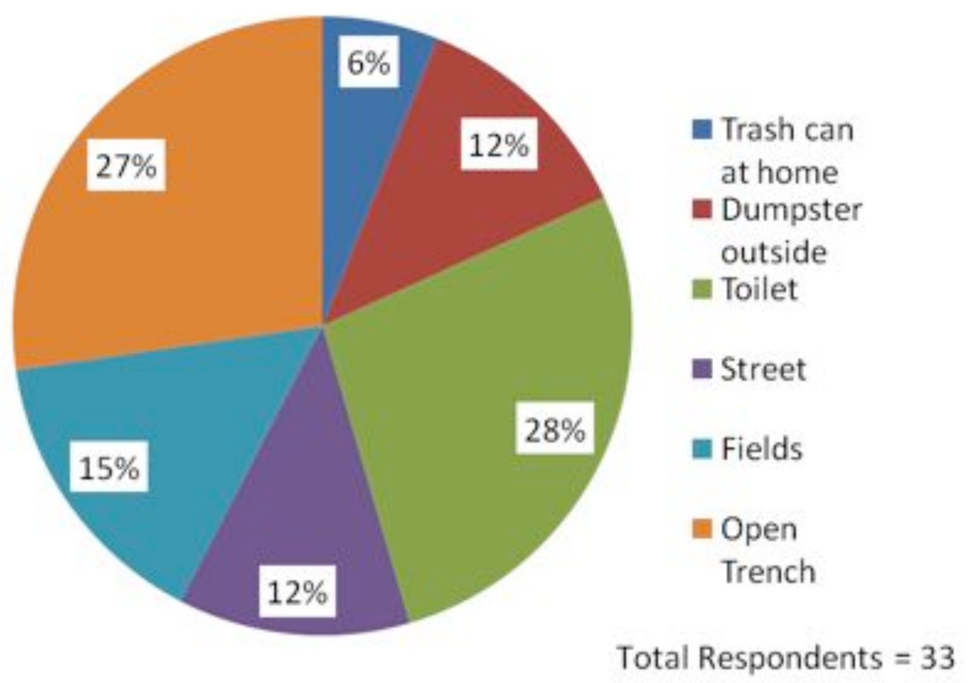
This begs the question: why? 15 residents were asked why they don’t use a private toilet; 11 of them report that children don’t use private toilets simply because they don’t have access to them. Reasons given for not using public toilets were much more varied; of the 25 people asked this question, 8 said it was because they are too young, while 5 said it was because the public toilets were too far away (see Table 2). The fact that the most popular answer was that they were “too young” implies a campaign specifically targeting children’s use of toilets is needed. Children are never too young to use a toilet; in fact, the earlier toilet use becomes the norm, the more likely the habit is to stick. While other concerns such as distance, cost, and cleanliness should also be addressed, people’s beliefs may be the biggest obstacle to ending open defecation among children.

Table 2: Residents' Explanations of Why Children Do Not Use Public Toilets

If they don't use a public toilet, why not?	Response	#		Response	#
	Don't know	1		Field is bigger	1
	Not allowed	1		Too expensive	1
	May slip	0		Have to pay	3
	Too young	8		Don't understand	1
	Too dirty	1		Isn't one here	2
	Too far away	5		Not comfortable	1

Likewise, the majority of mothers with children under the age of 5 dispose of their children's feces in dangerous ways: in the street, in the fields or in an open trench (see Figure 26). Each of these disposal methods allows for easy communication of waterborne pathogens through the environment. This is a serious problem which could reduce the incidence of diarrhea if addressed, through education and increased access to toilets and solid waste collection.

Figure 26: "Where do you dispose of children's feces?"



Conclusions and Recommendations

Health Education

In summary, we find that there is a large lack of awareness in the communities we surveyed about the existence of contamination in the drinking water, the principles of disease transmission and causes of illness, and the methods available to treat water. The first step for any intervention to improve the quality of drinking water and to reduce the water-borne disease burden, therefore, is to increase knowledge and awareness among key members of the community.

Based on our survey, people do not understand the basic pathways of transmission through the fecal-oral route. They understand that soap is important for washing, but they don't understand the when it is important to wash. There is minimal understanding of the need to treat their drinking water, and little awareness of low-cost treatment methods. People also clearly do not understand the importance of having children use the toilet, although it is unclear if adults who practice open defecation are doing so due to ignorance of the consequences or due to lack of access.

Based on our survey results, we believe that women – and mothers of young children in particular – are the most effective targets for such information. Mothers are most often responsible both for caring for sick children, as well as collecting and treating the drinking water. Furthermore, the majority of mothers work as homemakers, meaning that they are in the home for most of the day and therefore have the most time to implement a treatment method. The home may also serve as an important point of access through which to dispense this information, perhaps through door-to-door campaigns or with the assistance of a local health worker.

Awareness interventions in June and July of 2009 have included working with local doctors to set up meetings in their clinics at which we present demonstrations showing how water becomes contaminated – both in the home and in the pipes – and then present the options available for treating it. We have conducted similar meetings for the parents of the fourth standard students involved in our health education program. HMS has developed a double-sided pamphlet in Kannada which briefly discusses the importance of safe drinking water and then provides information on the effectiveness of treatment options as well as their cost and where to purchase them.

Access and Affordability

Beyond awareness, the survey results also demonstrate a need for less expensive water treatment alternatives in Hubli. This is especially critical given the fact that mothers – our target audience – are not usually responsible for decisions regarding the purchase of expensive items. Therefore, promoting something as costly as a candle filter (about Rs. 500) would require accessing and convincing the fathers in the household, which is more difficult logistically. Furthermore, the fathers are usually not as responsible for caring for children with diarrhea, so they may be more difficult to convince that there is a need for water treatment.

HMS has already acted on this need for a low-cost treatment option, by setting up a supply chain for Safewat sodium hypochlorite solution, which costs only Rs 15 and will last a household an entire month. We have also been selling Safewat at the awareness meetings from our own stock that we purchased in Mumbai en route to Hubli, and the receptiveness of the community towards this new option is extremely encouraging. As to be expected based on the survey results, once residents (particularly mothers, who are the primary audience at these clinic and school meetings) are made aware of the water situation and presented with a low-cost solution, their willingness to pay has thus far exceeded our supply.

Particularly when coupled with safe water storage (i.e. a container with a sealed lid and a spigot or tap to access the water), Safewat provides an effective treatment method (in this case HMS considers it effective because of the low likelihood that parasites have infiltrated HDMC piped water. If parasites are present, Safewat alone is not an effective treatment method). HMS has negotiated with a plastics distributor on Koppikar Road to produce these safe water storage containers (with taps pre-installed) at a cost of Rs. 120 for an order over 10 containers. We are currently searching for stores located in our slum neighborhoods who can buy these containers from the distributor in bulk and sell them to the community for a retail price of around Rs. 150 each.

As mentioned in the above section on Perception and Incidence of Disease, the average household spent Rs. 300 on treatment for diarrhea in the previous month alone. If just two months of diarrhea could be prevented each year, this would more than make up for the cost of a candle filter and enough Safewat to last for the entire year. The difficult arises because a household must make the initial investment of around Rs. 500 *before* they can begin to realize the economic benefits of a healthier family. Our survey shows that a significant number of families have a bank account and therefore have access to some savings and financial literacy, so this upfront cost may be acceptable for these families. For the remaining ¾ of households, HMS has been exploring partnerships with local microcredit organizations that can foot the initial bill and be responsible for collecting payments weekly. In addition, pursuing a partnership with Navodaya Swasahaya Sangha women's microfinance group seeking female entrepreneurs who are interested in promoting and selling any of these water treatment options (Safewat, safe water storage containers, and/or candle filters) in their local communities. The benefits of this system would be two-fold: first, it would provide income generation and cycle profits back into the local economy; secondly, these women would be locally known community members who would likely be well received if they were to promote their products by providing information on the need for them and their proper use.

Sanitation

Although respondents reported a high level of soap usage, they did not articulate the times when hand-washing is most needed. Also worrying is the observation that few people had water and soap available near their toilet. This implies that encouraging basic hand-washing could be a promising way to fight the spread of waterborne pathogens.

Our survey clearly indicates the need for increasing use of and access to safe toilets. Preventing contamination of the inhabited environment is an important way to block the fecal-oral route at the source. It is alarming that most households with private toilets discharge their blackwater, untreated, into open channels. These households might be the hardest to reach, since modifying existing infrastructure would be more challenging than building completely new toilets. Certainly, the low-hanging fruit would be to target those without private toilets but who own the land their house is on. According to the survey, this is approximately 34% of the population; such a project could be conducted on a reasonably large scale, if a scalable model could be created. Based on the household income data, HMS does not believe that private toilets are within reach for all of the people within this target group; public toilets should also be pursued at the same time for those who can't afford a private toilet.

Along with increasing access, people should be educated on the pathways present in the fecal oral route, in order to ensure that increased access translates into increased usage. This is especially true for toilet usage among children and for the disposal of feces by mother's with small children. HMS already targets children with its Health Education program; increasing access to sanitation at schools would give a further boost to these efforts. Although finding sufficient resources to pay for the operation and maintenance of school toilets would be difficult for Hubli's public schools, HMS is looking into innovative ways of creating new revenue streams through waste re-use programs. HMS is targeting mothers with an education program held at Aganwadis and local health clinics.

Until wastewater treatment occurs at the end of the pipeline, HMS does not support increased sewerage connections. Installing such connections does not remove pathogens from waste, it simply transfers them downstream. Although HMS would support community, or municipal, wastewater treatment plans, such projects would necessarily be done on a scale which is beyond the capabilities of HMS at this time. But his does not rule out their possibility in the future.

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Appendix 2:

Hubli Household Survey by Field Contact.

APPENDIX 2

Hubli Household Drinking Water Storage Container Survey by Field Contact

Container Survey	Number	Container type	Location	Size	Material	Shape of opening	Cover	Picture
Household	How many drinking water containers do they use for the days without water?	How many of each shape? A. Steel Tank B. Matka C. Other	Where is the majority of containers placed in the home? A. Above waist height B. Below waist height	Measure the height and width of the biggest container. Mouth and Width measurements are in circumference!!	What is the biggest container made of? A. Stainless steel B. Clay C. Plastic D. Other	Shape of the top of the container	How many containers are covered with a lid? Does the largest container have a lid?	Picture of largest container Check √
1	5	a == 1 steel tank	B (Below waist)	Steel Tank Ht-18inches, W-62 inches	stainless steel	Circle	2, yes	
2	8	a-1, c-1(cu) 6(pl) == 1 steel tank, 1 copper matka and 6 plastic matkas	B (Below waist)	Copper matka Ht-17inches, W-57inches, Mouth-26inches	Copper	Circle	2, yes	
3	5	a-4, c-1(pl) == 4 steel tanks, 1 plastic matka	A (above waist)	Steel matka Ht 11inches, W-35inches, Mo-22inches	stainless steel	Circle	2, yes	
4	3	a-2, c-1(cu) == 2 steel tanks and 1 copper matka	A (above waist)	steel tank Ht-19inches, W-42inches, Mo-42inches	stainless steel	Circle	2, yes	
5	8	a-3,c-5 (pl-4,cu-1) == 3 steel tanks, 4 plastic matkas and 1 copper matka	B (Below waist)	Steel tank Ht-19inches, W-41inches, Mo-41inches	stainless steel	Circle	2, yes	
6	5	A-1,C-4(cu-3,pl-) == 1 steel tank, 3 copper matka, 1 plastic matka	B (below waist)	copper matka Ht-17inches, W-65inches, Mo-28inches	Copper	Circle	2, yes	

APPENDIX 2

Hubli Household Drinking Water Storage Container Survey by Field Contact

Container Survey	Number	Container type	Location	Size	Material	Shape of opening	Cover	Picture
7	7	a-5, c-2(pl) == 5 steel tanks 2 plastic matkas	B (below waist)	Steel Tank Ht-18inches, W-41inches, Mo-41inches	steel	Circle	2, yes	
8	9	a-1,c-8(cu-2,pl-6) == 1 steel tank, 2 copper matkas and 6 plastic matkas	B (below waist)	Copper matka Ht-15inches, W-51inches, Mouth-26inches	Copper	Circle	2, yes	

3/12/10 conversation with Dev via gchat

There are 4 standard sizes of steel tanks. Largest one not shown here: height is 23 inches circumference is 48inches.

Additional notes

There are 4 standard sizes for steel tanks that can be bought. They come with their own manufactured fitted lids.

Steel tanks are pricey. Steel matkas are pricer. People prefer steel tanks to plastic because they are valuable (an investment) and don't break like plastic can.

Matka lids are plates (aluminum) or anything else around the house to serve as a cover. The "lids" that are improvised for matkas have other uses around the house as well.

People tend to primarily use steel tanks for accessing their drinking water. According to Dev, they tend to transfer water into the steel tank once it's empty from another container (some kind of matka). Potential reason might be ease of access - matkas have a smaller mouth and are harder to access water from. (another angle for us could be - easy access from ANY kind of container)

Sometimes containers full of water are also stacked on top of each other - the bottom on one serving as the lid for the other.

Standatd Stainless Steel Tank Size Dimensions

	Small	Medium	Large	Extra Large
Height (in)		18	19	23
Circum ference (in)	?	41 ???	41 -42??	48
Diameter (in)				

Appendix 3:

HMS Container Field Observations Document.

Comparison and Specifications of Selected Water Containers in Hubli
Ben Kallman
8/7/2009

<u>Matka</u>

The plastic matka seems to be one of the most widely used and omnipresent water containers in Hubli. While metal and ceramic matkas are popular, the often bright-colored plastic matka is seen practically everywhere you look, on or around most small food stands, in established restaurants for washing, in almost every house we visited, at bore well water tanks, in construction sites, and numerous other places. The plastic matkas are mainly used for transporting water. Their rounded shape and easily graspable neck (albeit unsanitary) allow for multiple methods of carrying. The prevalence of special matka carts (see image) suggests that matkas are used to *move* water. Their relatively small capacity (8, 12, 15, or 18 liters) allow for manageable lifting. People often carry plastic matkas on their shoulder, resting next to their head and being held by a single hand on neck. It's not uncommon to see a bright colored object bob up and down on someone's head. Their high concavity provides minimal splashing when being handles.

In houses that do not enjoy 24/7 water, the plastic matkas are used to transport water from the municipal tap (which often only runs for a few hours every 4-5 days) to their household water storage tanks (see below). Only the poorest households use matkas as permanent water storage devices. Although people do frequently drink out of matkas, their primary role is to transport water.

A cart specially designed to carry 6 matkas.


One method of drinking out of a matka


Capacity: 8 liters
Price: 25 Rs


Capacity: 12 liters
Price: 32 Rs

Capacity: 15 liters
Price: 50 Rs **Most popular**

Capacity: 18 liters
Price: 60 Rs

Steel Tank

The steel tank is the main method of drinking water storage in most low and middle-income households in Hubli. After retrieving water from the tap in a matka, the user will often pour the water through some sort of cloth or sieve for filtration (see image below). These steel tanks come in a variety of sizes, but the three most popular sizes are as follows:

	Height (in.)	Approx. Diameter (in.)	Capacity According to Shop Worker (L)	Calculated Capacity (L)	Price (Rs)
Small	16.5	12.18	18	31.5	425
Medium*	18	13.05	25	39.5	580
Large	23.5	16.23	60	79.6	780

*Most popular according to shop owner

These prices include a fitted lid that is *not* sold separately. The lid is also stainless steel and is specially made to fit these containers. It is not air tight, but does provide a good, tight fit. Users acknowledged concern over the difficulty in drilling a hold in their lid if they were to buy a separate water filter pump for their steel tank. It does not, however, make sense to force the user to buy a separate lid, as they are virtually impossible to acquire.


A birds-eye view of the container with lid


“Filtering” the tap water as it is being poured from the portable matka into the attractive, sleek steel water tank

This "filtration" is performed days in advance of drinking, allowing for plenty of time for contamination. Indeed, when the user removes water from the steel container, he or she will dip a small "lota" or steel cup into the container, probably contaminating the entire drinking supply.


Removing water using a lota Removing water using a glass

Houses will often have a whole collection of steel tanks to store water for the 4-5 day period between available piped water. They will use one at a time, switching to a different container when necessary, therefore switching a lid with a filter pump attached is not unreasonable. In fact, one person said, "it would be more convenient to pump out clean water than to pour the water through a cloth or sieve." (a two person job). Please watch the mpeg movie of a user filtering piped water through a cloth. It is not a trivial process. Of course, the fact that the user emphasized the *ease* of use instead of it's *effectiveness* highlights the lack of concern for good filtration techniques. The only reason said user would switch to a filter-pump is because of its apparent simplicity, not because it would be more effective. This is an important distinction.

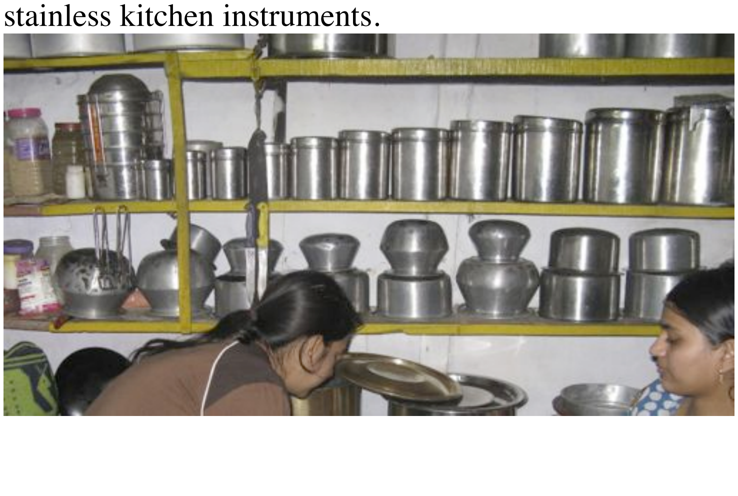

Two separate houses with similar collections of water storage devices

When asked how much a household was willing to pay for a filter-pump which would attach to the lid of their steel tank and pump out clean drinking water, 3 houses came up with a number between 200 and 250 Rs. The maximum willingness to pay was 300 Rs, although it's unclear whether or not a user would be willing to pay in installments for a number of months. I'm fairly certain that anything over 300 Rs would be a stretch to sell on a large scale. The price for any sort of filter or product must be extremely low. A candle filter costs 550 Rs. And is seen as a big investment. Its (relative) success lies in its similarity to other water storage devices. The fact that it is stainless steel is essential. The very first question I was asked when trying to determine willingness to pay for a filter-pump was "will it be stainless steel or plastic?" Clearly, this is a deciding factor in whether or not it is a viable water storage option. Indeed, one look at almost any kitchen in Hubli and you will realize how ubiquitous and important stainless steel is.

candle filter
Capacity: 36 Liters
Price: 550 Rs

A household kitchen supply shop.
Note that everything is stainless steel

The importance of stainless steel is not to be overlooked. Even slum families have shiny stainless kitchen instruments.



Steel tanks are often fitted with taps. Note the cloth filter. It is also important to note that many (if not most) families use steel tanks on the ground, making the barrier to creating a safe water storage container more formidable than just the price of the tap and its assembly.

Lota

The lota is the small metal container used for dipping into the large steel tank. A lota is bigger than a glass, so a user will often fill up a lota and then with it, pour out cups of water or pass it around for drinking. It is often stored on the lid of, or next to, the steel tank. See image above for a view of someone using it to dip out of a steel tank. While there are numerous different shapes and sizes, they are all mild versions of the supposedly (according to a shop worker) most popular type, which is 1 Liter in capacity and costs around 60 Rs.

The most popular type of lota
Capacity: 1 Liter
Price: 60 Rs

When doing Safewat observations, we encountered a house that used a 1-liter lota as a container in which to treat their water with Safewat. This is a very viable option as long as the user does not let this treated water sit for too long. The image above, of the rows of metal containers in the shop, shows only some of the possible types of lotas, all of which are mild variations on this shape.

Appendix 4:

Stakeholder Analysis.

APPENDIX 4

Stakeholder Analysis

Safe Water Storage; Hubli India.

Stakeholder	Interest in Project	Potential Impact on Project	Ally? Competitor? Opponent? None?	Stakeholder Importance	Participation plan
Adult women (Mothers in household)	Primary User, looking to: Decrease water collection time/energy, easy use of product for all potential users, and lowered rate of diahrreal illness	High Impact - as primary user, knowledge of how to use product is spread by her. Also she must be the first stakeholder to show interest	Ally - if the product meets her specifications (easy to use and adds convenience)	Vital - Primary User	Must be present during installation - must understand inner workings and repair options (How)
Adult Men (Fathers in household)	Looking for: Low cost fix that prevents illness; save money otherwise spent on illness; adds value to product; maintains/exceeds the current rate of water delivery	High financial impact, actual understanding of product is not essential - probably the only stakeholder with enough strength to break the product	Ally/Opponent - dependent on life-time of product, initial cost, and practicality (If it breaks too fast, costs too much, or doesn't work, he won't like it)	Vital - Financier	Must be made to understand that water cannot be touched (Why)
Children (Male/Female)	Wants to be able to do the household chore of water collection independently of mother; must also be able to retrieve water in a sanitary way unassisted, and the product have a usage that is different, accessible, and fun	Implementation will likely be unsuccessful without accodating for this group - this secondary user group likely outnumbers primary users	Wild Card - If children like the product, there will be strong enthusiasm and it may be more easily integrated into their lives; if there is a way to break/misuse the product, they'll find it	Vital - Secondary user	Understanding of usage is mandatory

APPENDIX 4
Stakeholder Analysis
Safe Water Storage; Hubli India.

Stakeholder	Interest in Project	Potential Impact on Project	Ally? Competitor? Opponent? None?	Stakeholder Importance	Participation plan
Teenage Male	Product can increase the independence of younger siblings; this group may find potential livelihoods in the construction of such products	Would be the person who does actual retrofit work, continues project in the absence of NGO as a source of regular wage	Ally - If the process is easily learned and reproduceable; materials must also be cheap	Wild card - If we can find enthusiastic/entreprenurial spirits in the community, these people will bring increased sales and exposure	Retrofit process must be tailored to his learning process
Teenage Female	Product can increase the independence of younger siblings; product adds permanent value which is possibly transferrable to her	Likely has similar responsibilities for children like Mother; facilitates education and enforcement of proper usage of the product to children	Ally - if the product is easy to use and adds convenience	Secondary	Same as adult women
Head of Household	Prestige of product; water quality changes (Taste); financial cost/added value; rate of water distribution	High - makes final decision on purchase of product; enforces proper usage of product	Ally/Competitor; does it require significant behavioral changes?	Vital - Final Decision Maker	Explain why the improvement is necessary and adds value
Shopkeeper / merchants	Initial Materials; upkeep/maintenance requirement; inclusion in new power structure	Will provide long-term supply chain; initial materials	Competitor/Ally - stocks alternative products or makes money off our product	Vital in long term, in absence of NGO workers	Provide bill of materials, costs/suppliers; understanding of innerworkings so they can do retrofits

APPENDIX 4
Stakeholder Analysis
Safe Water Storage; Hubli India.

Stakeholder	Interest in Project	Potential Impact on Project	Ally? Competitor? Opponent? None?	Stakeholder Importance	Participation plan
Upper Social Class	Maintain or increase their position over lower classes; attain real/perceived quality of life improvements before the lower class	assuming lower > upper class in numbers, upper class might be alienated if lower class receives technology first	Ally that can become an opponent - ally if the product is pitched to them first	Vital for initial sales/ word of mouth	If lid retrofitting is client based, targeting this stakeholder group first would be most beneficial
Donors	Want to see real measurable improvement in slum communities; each donor group has its own specific emphases/ world view	Amount of money dictates design quality/ logistics; public perception of our operations can be altered by donor group	Ally - wants to give you money!	Vital for logistics	submit reports/updates
Other NGOs	Want to see our strategies & implementation plans; wants access to our contacts and donors; could be interested in their own variation or alternative	multiple NGOs mean competing ideas in the idea marketplace, while the target population is not used to new ideas - activities could be synergistic (Failure reinforces failure, success reinforces success)	Ally/ Competitor	minor - not a target community group or source of funding	None or informal notifications

Appendix 5:

Siphon Tap v.1 Calculations.

APPENDIX 5

Siphon tap v.1 air space calculation

Siphon tap design
Rabia Chaudhry

Determining the length of pipe between the two valves
(Preventing water inflow into the bellows)

1cm	0.39370079 in
1cm3	0.06102374 in3

L = 4*V/ (pi * D^2)

Copper tubing (nominal sizing not based on OD or ID)

Volume of bellows (mL or cm3)	V = volume of bellows (cubic inches)	copper tubing size (inches)	OD of copper tubing (inches)	D = ID copper tubing (inches)	L = Length of tubing needed (inches)
	8.3	3/8ths	0.5	0.436	55.6
	8.3	5/8ths	0.75	0.62	27.5
	8.3	3/4th	0.875 (7/8th)	0.811	16.1
	8.3	1	1	0.936	12.1
100	6.10	3/8ths	0.5	0.436	40.9
100	6.10	5/8ths	0.75	0.62	20.2
100	6.10	3/4th	0.875 (7/8th)	0.811	11.8
100	6.10	1	1	0.936	8.9
60	3.66	3/8ths	0.5	0.436	24.5
60	3.66	5/8ths	0.75	0.62	12.1
60	3.66	3/4th	0.875 (7/8th)	0.811	7.1
60	3.66	1	1	0.936	5.3
30	1.83	3/8ths	0.5	0.436	12.3
30	1.83	3/4th	0.875 (7/8th)	0.811	
30	1.83	5/8ths	0.75	0.62	6.1
30	1.83	1	1	0.936	2.7

Volume of bellows bought	D = 2.5"	
	H = 1.7"	
	V (in3)	8.34479531
Spring compression threshold		
Force of column of water 8"	Volume (in3)	4.81052906
in 7/8" OD tube	density lbs/in3	0.03612729
F = Volume*density*g		
	Force (lbs)	0.17

Should not flow without additional force from bellows compression